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THE WORLD'S LARGEST TELESCOPE

By GEORGE ELLERY HALE
Director of the Mt. Wilson Observatory

Casting the 200-inch reflector, though an achievement of such moment as to rank with the best traditions of the Corning Glass Works, is none the less only one of the many difficulties involved in the building of the greatest telescope the world has ever known. The planning of this larger enterprise—selecting a site for the observatory, building the framework to support the 20-ton reflector, grinding a concave glass surface nearly 17 feet in diameter to a true paraboloidal form within tolerances of two millionths of an inch, and finally assembling the complete, gigantic telescope—is a fascinating story. It is told here by a man well qualified to write it, Dr. George Ellery Hale. The article was written for Atlantic Monthly and a part of it is given here through courtesy of the publishers. It will lay the groundwork for a later discussion of the big disk itself, which will be written for GLASS INDUSTRY by Dr. George V. McCauley, in charge of the operations at Corning Glass Works.

SIXTY centuries ago, on the banks of the Nile, the pioneer astronomers of Egypt watched the meridian passage of the stars and mapped the principal constellations. Hundreds of Bablonian tablets also preserve astronomical records, which were continued for centuries and led to the capital discovery of the procession of the equinoxes. In those early days the great distance of the stars was unknown; but, as the centuries rolled by, the heavenly bodies seemed to recede from the earth. Increased precision of observation showed the stars to be very remote, and enhanced the desire for greater knowledge.

At the end of the 17th century the only known stars were the small number visible to the naked eye. Then came Galileo's telescope. Suddenly tens of thousands of hitherto unseen stars burst into view, and with them the mountains of the Moon, the satellites of Jupiter, and the phases of Venus. Thus the reasoning of Copernicus, who had placed the sun instead of the earth at the centre of the solar system, was finally confirmed. The telescope continued to grow, recently attaining a diameter of 100 inches and revealing thousands of millions of stars. During the last century its efficiency has been greatly enhanced by combining with it such chemical and physical devices as the photographic plate, the spectroscope, and the photo electric amplifier.

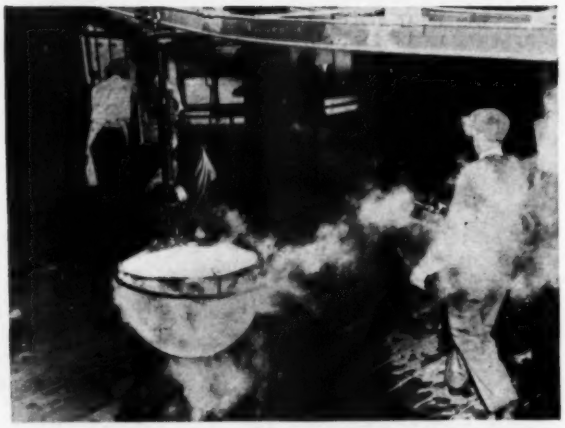
In 1928, the Rockefeller Trustees offered to the California Institute of Technology a sum sufficient to build a 200 inch reflecting telescope, together with such instrument shops, laboratories, and other facilities as would be required to establish a well-rounded Astrophysical Observatory. This observatory was designed to be complimentary to the Mount Wilson Observatory, and in no sense a rival institution. Research laboratories and observatories should not be organized as competing institutions, largely intent on their own glory. On the other hand, a group of observatories should not be conducted as unthinking machines, operated by a single head. Whenever possible, plans of cooperation should be devised, in which all of the originality of each individual investigator is stimulated and encouraged without sacrifice of the great advantages of joint operation and control.

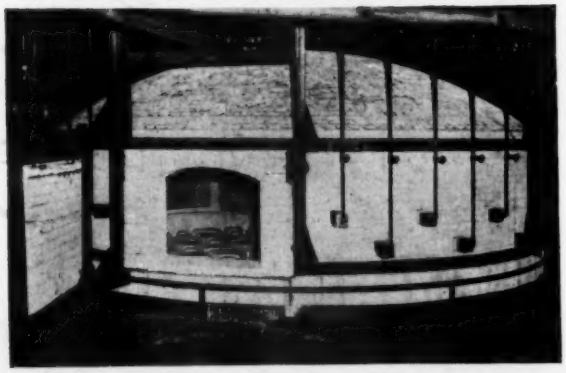
A necessary condition of the Rockefeller gift was therefore that the Carnegie Institution of Washington should cooperate in the most complete way with the Californian Institute. Such cooperation was cordially promised by the President and Executive Committee of the Carnegie Institution. Reciprocally, the California Institute offered the use of its facilities to members of the staff of the Mount Wilson Observatory. The Institute's Physical and Chemical Laboratories, not to speak of the possibilities of its new astrophysical equipment, will thus be available for researches needed by the Mount Wilson observers.

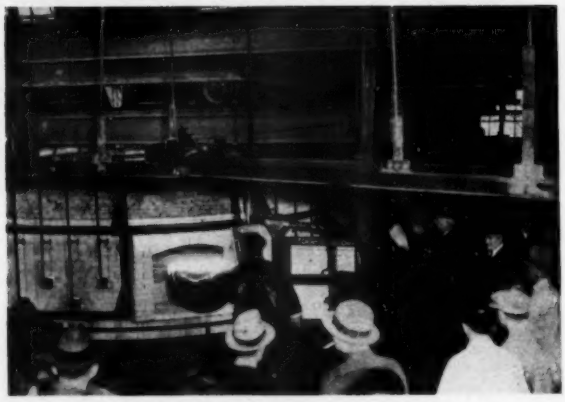
The problems involved in constructing and operating a greater telescope are easy to name but difficult to solve. The first necessity is to make disks of glass or some other suitable material of sufficient size, stiffness, homogeneity, and freedom from marked distortion by change of temperature.

The next is to give such a disk a practically perfect optical surface and to coat its curved face uniformly with a highly reflecting film of silver or other suitable metal.

While this process, involving many years of work, is under way, a telescope mounting must be designed and built. This must be capable of supporting the massive optical disk so perfectly that it will be undistorted in any position. It must also automatically follow the stars with great precision throughout the night.







Photos by Acme and Times World Wide Photos.

At the same time a careful comparitive study must be made of promising sites for the telescope, in a region where much clear weather and other favorable conditions prevail. The long construction period will also give opportunity for other work of equal importance, including the erection of shops and laboratories and the design and construction of auxiliary apparatus capable of multiplying many fold the efficiency of the telescope.

Throughout the centuries separating Galileo from the earliest astronomers, the only collector of starlight available was the unaided eye. The huge astronomical instruments erected in Cairo, India, Denmark, and elsewhere revealed no stars beyond the range of ordinary vision; they served merely to determine the positions and motions of the visible stars and planets. Although lenses had been used earlier as aids to vision, Galileo was the first to apply them to the heavens. His telescope, with its simple convex lens about two and one-quarter inches in diameter, collected about eighty times as much light as the pupil of the eye. This gain was sufficient to add hundreds of thousands of stars to the two or three thousand previously seen. Now it is a question, not so much of multiplying the hundreds of millions of stars already known, as of brightening their images and of making possible a satisfactory exploration of the vast world of distant galaxies lying beyond the limits of the Milky Way.

After years of ingenious experimentation by the General Electric Company with fused quartz, which offers hitherto insuperable difficulties in very large masses because of its extremely high melting point, we turned to Pyrex glass, so widely known because of its superiority to ordinary glass for cooking purposes. Its high quartz content greatly reduced its expansion by heat, and explains why Pyrex utensils withstand without cracking the sudden changes of temperature to which they are often exposed. The casting and annealing of large Pyrex disks demanded, however, extensive studies by experienced physicists, and we were very fortunate to be able to call upon the knowledge and experience of Dr. Arthur L. Day, Director of the Geophysical Laboratory of the Carnegie Institution of Washington, and the able research staff of the Corning Glass Works.

After a 60-inch Pyrex disk had been successfully made, a glass much superior for our purposes to ordinary Pyrex was developed for us, and used to make the 72-inch disk for the telescope of the new Toronto Observatory. A 120-inch disk (needed for testing the 200-inch mirror) was then cast for us last June. It was carefully annealed by a special process, and when taken from the annealing furnace in December it was shown by preliminary tests to be of the highest quality. On the last day of the year, an 80-inch disk, for the new observatory of the University of Texas, was cast at Corning from the same kind of glass. Thus the Rockefeller gift to the California Institute is accomplishing the purpose of developing new methods and materials needed by many institutions, instead of being solely devoted to the establishment of a single new observatory.

A 120-inch disk having been cast, with an area half again as great as that of the largest telescope mirror previously made, we may look forward with confidence to the success of the 200-inch disk, the annealing of which should be completed by the beginning of 1935.

Then follows the long and delicate process of grinding, polishing, and figuring the disk in Pasadena.

At this point a word should be said regarding the preparations already made at the California Institute. The first need was a suitable machine shop, equipped with the tools required to build the special instruments, of many new types, called for in this enterprise. Here, too, a large grinding and polishing machine has been designed and built. This machine is nearly ready for work on the 120-inch disk in our new optical shop, completed a few months ago. No such building is available elsewhere, because of the large scale requirements of the task. It must not only permit the 120-inch and 200-inch disks to be ground, polished, and figured to the highest perfection, but also to be tested optically in combination with each other. These operations demand a room 54 feet wide, 162 feet long, and 39 feet high, in which the dust-free air can be maintained for many months at nearly constant temperature and humidity. Overhead an electric crane, tested for loads of fifty tons, spans the room and travels its entire length. By this means the heavy disks can be lifted on or off the polishing machines and moved about at will. Small optical shops adjoin the main room and afford space for all the minor work. When finally completed, the 200-inch mirror will have a polished concave face, not differing from a true paraboloidal form by more than two millionths of an inch.

The ordinary method of coating such a telescope mirror is to deposit on it chemically a very thin layer of pure silver. Four years ago, however, John Strong developed at the University of Michigan a process of vaporizing various metals, and depositing the vapor on glass or any other substance in a high vacuum. Now a member of the research staff of the California Institute, Strong has recently coated with aluminum mirrors up to thirty-six inches in diameter (the Crossley Reflector of the Lick Observatory), besides many smaller mirrors and gratings used on Mount Wilson and in Pasadena. The remarkable permanence of such aluminum surfaces and their great superiority to silver, especially in the violet and ultra-violet, lead us to hope that this process can be used for coating the 200-inch mirror.

Photographic exposures of faint celestial objects often last for hours, or even for several successive nights. During this time the stars must be kept accurately in position on the plate, in spite of their apparent westward motion caused by the rotation of the earth. The 200-inch mirror, weighing nearly twenty-five tons, must therefore lie on a special support system (to prevent distortion) at the bottom of a steel skeleton tube hung on trunnions between the arms of a huge polar axis, kept in steady rotation by a driving clock and worm gear. The skeleton tube, about twenty-five feet in diameter and sixty feet long, will be so rigid that the observer can be carried at its upper end, within a small cartridge-shaped house at the centre of the tube. The parallel rays of light from the stars, entering the open end of the tube unimpeded except by the central observer's house and its four narrow supporting steel webs, will fall on the concave mirror at the lower end of the tube and be reflected back to form images which can be observed visually, photographed, analyzed with a spectroscope, or

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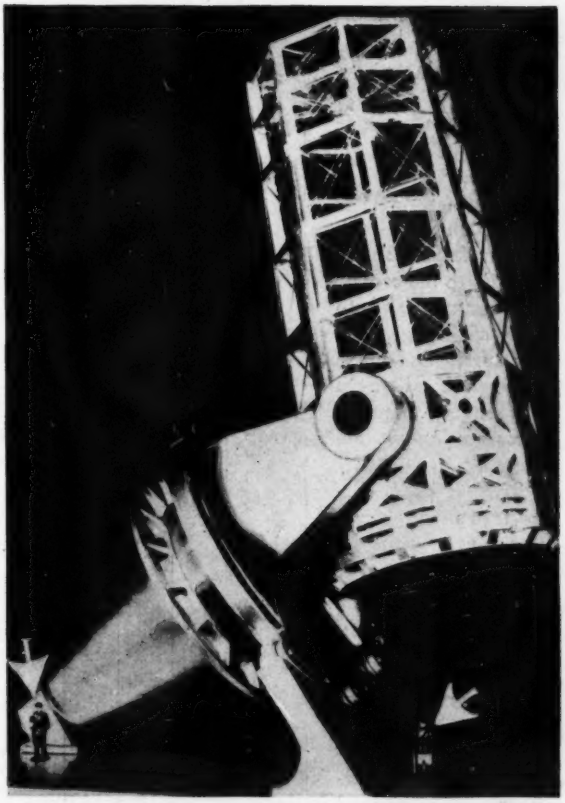

SCENES AT CORNING GLASS WORKS DURING THE CASTING OF THE 200-INCH DISK

On this and the page facing, the reader can follow the glass as it is taken from the furnace and transported to the mould. Then the mould itself, and the glass as it is poured. Immediately above is a model of the telescope as it will look when completed, with models of two men nearby to indicate its height.

THERMAL EXPANSIONS OF SODA-LIME-SILICA GLASSES AS FUNCTIONS OF THE COMPOSITION

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THIS report* is the third of a series of studies on the relation between chemical composition and properties of some soda-lime-silica glasses. In the first report, relating to index of refraction,[1] the purpose of the general study was given, the method of making the glasses detailed, essential parts of the methods of chemical analyses were outlined, and the character of annealing was described. The second report contained the results obtained with respect to density,[2] and the present paper gives the results obtained by measuring the thermal expansion of 37 of the glasses used in the previous studies and 12 additional glasses made especially for the current study. Of the total number 19 were soda-silica and 30 were soda-lime-silica glasses, the composition varying so that the former contained approximately from 17 to 50 per cent soda and the latter from 3 to 20 per cent lime.

The linear thermal expansion of each glass from 25 to 400°C., to the critical temperature, and to the softening temperature, and also these critical and softening temperatures are included in the data presented.

Method used. Expansion measurements were made by the interferometer method described by Peters and Cragoe,[3] which consists essentially of placing three small truncated cones of glass about 5 mm high between two optically flat fused-quartz disks and counting the number of interference fringes which pass a reference point in the viewing apparatus as the temperature of the furnace is raised approximately 3°C per minute.

Expansion measurements were made in duplicate on all the soda-lime-silica glasses, and the second measurements were regarded as the more satisfactory because such measurements were, in general, more nearly reproducible than those obtained in the first test. In all cases of duplication the data reported are from the second test. Because of the unstable (hygroscopic) nature of most of the soda-silica glasses and the consequent difficulty in handling them, their expansions were in many cases measured only once and the data, except for a few of the more stable glasses, are based on single tests.

Data Obtained and Results. The composition of each glass, the expansion from 25 to 400°C, the critical temperature, the expansion from 25°C to the critical temperature, the softening temperature, and the corresponding expansion are given in table 1. The viscous deformability of a glass increases rapidly between the so-called critical and softening temperatures. At the critical temperature the rate of deformation is too low to result in measurable deformations under the conditions of operation in these expansion tests; as the softening temperature is approached, however, the rate of deformation becomes so great that it results in a fairly rapid and measurable flattening of the bearing points of the test specimen under the weight of the interferometer plate. When determined under the same experimental conditions, these tempera-

Table 1. Compositions, Observed Critical and Softening Temperatures, and Linear Thermal Expansions Between the Indicated Temperatures.

Glass No.[1]	Composition[2] SiO_2	Na_2O	CaO	Expansion[3] (25 to 400°C)	Critical temperature[3]	Expansion[3] (25°C to critical temp.)	Softening temperature[3]	Expansion[3] (25°C to softening temperature)
	%	%	%	*Microns per cm*	°C	*Microns per cm*	°C	*Microns per cm*
1 (13)	52.15	47.85	------	81 (+2)	----------	----------	440 (0)	95 (+2)
2 (6)	54.14	45.86	------	76 (0)	426 (+2)	84 (−1)	450 (+3)	94 (+1)
3 (8)	57.45	42.55	------	73 (+2)	428 (−5)	81 (−1)	460 (+3)	89 (−1)
4 (12)	59.97	40.03	------	70 (+2)	442 (+2)	80 (0)	460 (−5)	85 (−2)
5 (14)	62.86	37.14	------	66 (+2)	445 (−2)	76 (0)	470 (−4)	82 (−2)
6 (16)	65.30	34.70	------	61 (+1)	457 (+4)	73 (0)	490 (+7)	80 (−1)
7 (19)	67.14	32.86	------	58 (0)	460 (+2)	69 (−2)	490 (+2)	77 (−2)
8 (20)	69.65	30.35	------	55 (+2)	470 (+5)	67 (0)	505 (+9)	76 (0)
9 (21)	70.21	29.79	------	55 (+2)	470 (+3)	68 (+2)	500 (+2)	76 (+1)
10 (22)	70.44	29.56	------	55 (+3)	467 (0)	68 (+2)	500 (+1)	77 (+2)
11 (23)	72.15	27.85	------	51 (0)	473 (+2)	64 (0)	500 (−4)	72 (0)
12 (28)	76.60	23.40	------	44 (+1)	480 (−3)	56 (0)	510 (−8)	63 (−1)
13 (29)	76.65	23.35	------	44 (+1)	485 (+2)	58 (0)	510 (−8)	65 (0)
14 (31)	77.85	22.15	------	41 (0)	486 (−1)	53 (−1)	525 (+3)	63 (0)
15 (32)	78.61	21.39	------	40 (0)	490 (+2)	53 (0)	520 (−4)	60 (−1)
16 (33)	79.73	20.27	------	38 (0)	489 (−1)	50 (−1)	530 (+2)	57 (−2)
17	80.04	19.96	------	38 (0)	492 (+5)	50 (0)	525 (−4)	55 (−3)
18	82.72	17.28	------	34 (0)	495 (−5)	45 (0)	540 (+2)	53 (0)
19 (34)	82.76	17.24	------	34 (0)	500 (0)	45 (0)	550 (+12)	52 (−1)
[4] 20 (38)	100	------	------	----------	1,020	5	1,140	6
21	52.20	27.97	19.83	59 (−1)	498 (−7)	80 (0)	535 (+3)	90 (0)
22 (41)	54.37	32.85	12.78	62 (−3)	477 (+1)	79 (−2)	505 (−3)	83 (−6)
23 (42)	56.20	34.00	9.80	67 (0)	470 (+1)	84 (+5)	495 (−6)	90 (+2)
24	56.34	23.91	19.75	51 (−1)	517 (−10)	73 (−3)	550 (−4)	80 (−6)
25 (43)	56.76	37.48	5.76	67 (0)	444 (−9)	77 (−4)	480 (−4)	87 (−3)
26 (44)	58.41	38.54	3.05	68 (+1)	437 (−9)	77 (−2)	473 (−3)	88 (−2)
27	60.05	19.79	20.16	49 (+1)	548 (−2)	74 (+3)	580 (+1)	81 (−1)
28 (45)	60.32	24.50	15.18	52 (0)	520 (+1)	74 (+1)	547 (−3)	79 (−3)
29	62.93	17.39	19.68	43 (−1)	568 (+3)	69 (0)	595 (−1)	77 (−1)
30 (46)	63.34	24.39	12.27	52 (+1)	518 (+5)	74 (+2)	550 (+2)	81 (0)
31 (47)	64.14	21.22	14.64	47 (0)	530 (−5)	69 (0)	570 (+1)	76 (−2)
32 (48)	64.70	26.84	8.46	52 (0)	493 (−2)	71 (+1)	530 (−2)	81 (+2)
33 (49)	65.71	28.79	5.50	53 (0)	493 (+12)	72 (+2)	515 (−1)	79 (0)
34	66.05	17.92	16.03	44 (+1)	563 (+6)	69 (+3)	595 (+5)	78 (+2)
35	66.12	13.97	19.91	40 (+2)	587 (0)	67 (+1)	625 (+3)	77 (+2)
36 (50)	66.47	21.74	11.79	48 (+2)	522 (−4)	72 (+6)	560 (−2)	84 (+8)
37	67.23	11.62	21.15	37 (+2)	601 (−2)	64 (−1)	645 (+1)	75 (0)
38 (51)	67.30	29.43	3.27	53 (0)	480 (+7)	69 (−1)	515 (+5)	78 (+1)
39 (52)	67.98	22.50	9.52	47 (0)	518 (+1)	68 (+2)	560 (+6)	82 (+7)
40	70.12	15.03	14.85	39 (+1)	567 (−9)	63 (+1)	610 (−1)	73 (+2)
41 (53)	70.50	23.00	6.50	45 (−1)	506 (0)	62 (−1)	545 (−1)	73 (0)
42	71.70	12.10	16.20	35 (+1)	598 (−2)	60 (0)	630 (−6)	65 (−3)
43 (54)	72.08	14.21	13.71	36 (0)	571 (−8)	59 (−1)	615 (0)	68 (−1)
44 (55)	72.61	24.24	3.15	46 (+1)	490 (−2)	61 (0)	530 (+1)	72 (+1)
45 (56)	74.09	15.23	10.68	36 (0)	555 (−8)	57 (−2)	600 (−1)	68 (+1)
46 (57)	74.69	12.28	13.03	33 (−1)	589 (−4)	57 (0)	627 (−4)	66 (−1)
47 (58)	75.48	15.26	9.26	36 (0)	553 (−5)	54 (−3)	600 (+3)	65 (0)
48	78.56	18.45	2.99	38 (+1)	504 (−7)	52 (−1)	545 (−8)	60 (0)
49 (59)	78.77	16.33	4.90	34 (−1)	523 (−8)	51 (−1)	565 (−9)	61 (+1)
50 (60)	80.59	16.17	3.24	32 (−2)	505 (−17)	43 (−6)	560 (−1)	55 (−4)

[1] Figures in parenthesis in this column are the numbers of the corresponding glasses in the report cited in footnote 2 of the text. Additional glasses made for this study have only 1 number.

[2] The methods of analyses of these glasses are discussed in the reports cited in footnote 1 of the text.

[3] Figures in parenthesis in these columns are the algebraic differences, to the nearest whole number, between the observed values and those obtained by computation or from the graphs in figures 1, 2 or 3; + differences indicate observed values greater than computed values.

[4] The data on fused quartz (not published) were furnished by G. E. Merritt and are the average from several samples which were neither made nor analyzed at the Bureau of Standards.

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tures are rather characteristic of a given glass and it is presumed also that under such conditions they give a fairly good method of showing at what temperatures different glasses reach comparable deformabilities.

The critical temperature, or the temperature at which the rate of expansion definitely increases, was regarded as the temperature at which a straight line drawn through four or five consecutive points on the expansion-temperature curve departed definitely from a line drawn through the next higher points.

The softening temperature for any glass was relatively easily determined because, for the purpose of this paper, it was regarded as the temperature at which the glass became so soft that its rate of shortening by deformation was equal to its rate of expansion and the movement of the interference fringes practically ceased. This point was followed by a reversal in the direction of movement of the fringes, caused by increasing deformation of the specimens.

Since the temperature at which expansion measurements were started varied between 25 and 39°C, all expansions were "corrected" to 25°C as a starting point. This extrapolation was made on the assumption that the rate of expansion between 100 and 200°C is practically constant and equal to the rate between 25 and 100° C. The maximum "correction" was 2 microns, the average being less than 1 micron.

The critical and softening temperatures of the soda-silica glasses and corresponding expansions (all obtained as described above) and also the expansions to 300 and 400°C are plotted in figure 1 against the soda content.

If the expansions from 25°C to any specific temperature, T, below the approximate critical temperature are considered, it was found that these expansions can be computed from equations of the familiar form $E=aA+bB+cC$, in which E is the linear expansion in microns per centimeter; A, B, and C are the percentages of silica, soda, and lime, respectively, and a, b, and c are constants determined for a given temperature. The values of these constants for each interval 25°C to T, as T was increased by 50°C steps from 50 to 450° C, were determined by making independent solutions by the method of least squares, and by using the expansion values of the various glasses as read from the individual expansion curves corrected to 25° C. The soda-silica and soda-lime-silica glasses were treated separately. In this way it was found that a, b, and c are functions of temperature fitting very closely the equations:

$$a=0.00036t-0.00000036t^2$$
$$b=0.00245t+0.0000046t^2$$
$$c=0.00116t+0.0000010t^2$$

where $t=T-25°C$. The coefficients of t and t^2 for a, b, and c, respectively, were obtained by the method of least squares, using the various values of a, b, and c, determined as indicated above, for the different temperature intervals. The numerical values shown are those obtained from the soda-lime-silica glasses only. Although a solution of the soda-silica glasses gave only slightly different equations for a and b, less weight should be attached to them because, as previously stated, they are based on the first determinations (second determinations being used for the lime-glass data). For the purpose of evaluating the constants, no temperature above 450°C was used, since many of the glasses are approaching their

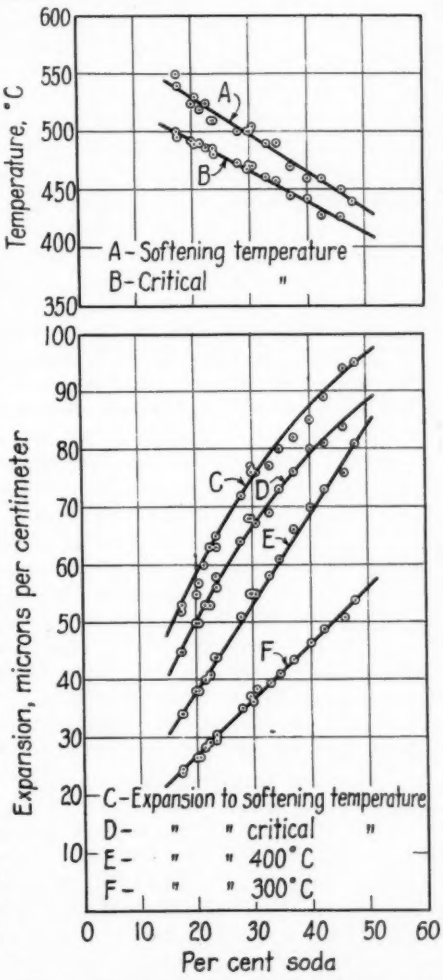


Fig. 1. Showing relations between composition, critical and softening temperatures and linear expansions of some soda-silica glasses.

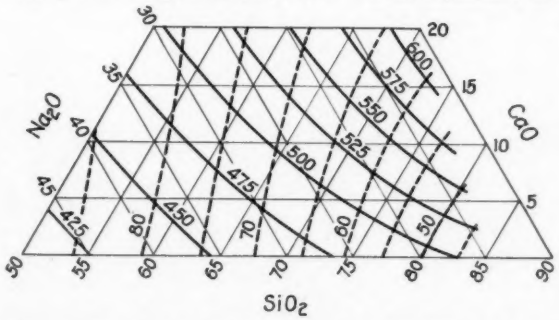


Fig. 2. Showing relations between composition of some soda-lime-silica glasses and critical temperatures (solid lines) and also linear expansions (broken lines) to those temperatures. Temperatures are given in C and expansions in microns per cm.

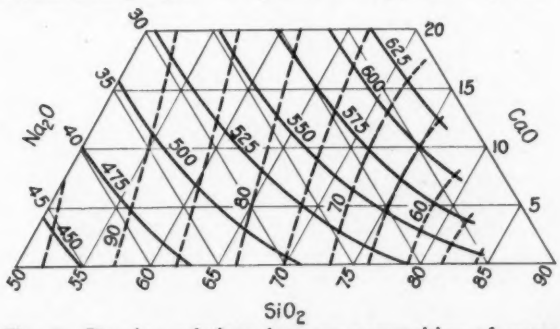


Fig. 3. Showing relations between composition of some soda-lime-silica glasses and softening temperatures (solid lines) and also linear expansions (broken lines) to those temperatures. Temperatures are given in C and expansions in microns per cm.

critical temperatures at this point, and hence any solution involving data above 450°C would be of doubtful value. The equations were found, however, to be adequate within about 50°C of the critical temperature for any glass, a few such temperatures being as high as 600°C. The average deviation increases with temperature, being about 0.3 micron at 50°C and about 1.5 microns at 550° C, (the corresponding maximum deviations being 1 and 3 microns respectively) and at no temperature is there a noticeable systematic deviation, as long as no glass is considered after it comes within 50° C of its critical temperature.

Graphs E and F in figure 1 show observed linear expansions of the soda-silica glasses at 300 and 400° C, and also the lines obtained by solving the equations given above for E, a, and b being evaluated at these temperatures.

Based on the data obtained, several different kinds of empirical equations for computing the critical and softening temperatures and the expansions from 25°C to these temperatures for a given glass in either series can be devised. The following empirical relations were used, however, to compute the residuals presented along with the last four columns in table 1. For both the critical and softening temperatures

$$T=d+e(B+C)+p\left(\frac{C}{B}\right)+q\left(\frac{C}{B}\right)^2$$

For the expansion to both temperatures

$$E=f+gB+hB^2+r\left(\frac{C}{B}\right)^n$$

In these equations B and C are the percentages of soda and lime, respectively, and d, e, f, g, h, p, q, r, and n are constants having somewhat different values in computing the data relating to the critical and softening temperatures. For example, p, q, f, and r remain practically unchanged, while h, the coefficient of B^2, changes approximately 30 per cent. Actual use of numerical values for these constants was not made, however, since a graphic method based on the above relations was found to be both simpler and adequate for determining both the differences (see table) and the lines (see figs. 2 and 3), which show how the composition of these glasses may vary without changing one of the following: The critical temperature, the softening temperature,[4] or the expansion to one of these.

Reproducibility and Accuracy of Results. Generally any one glass gave reproducible expansion measurements within 1 or 2 microns and temperature measurements within 5 degrees if the same specimens were used for a second series of measurements. The average difference between duplicate measurements of the expansions to the softening points, of the 34 glasses on which two tests were made, was 2 microns; measurements on 23 of the glasses varied 2 microns or less, on 5 glasses the difference was 3 microns and on the remaining 6 the average was 6, the maximum being 8 microns.

To demonstrate the effect of the shape of the sample on these results, two sets of specimens were prepared. For one of these the truncated cones were very stocky; that is, they were relatively broad at the base, with only a slight taper and relatively flat, though rounded, at the top. For the other, the specimens had a smaller base and the cone was reduced to the equivalent of a very slender rod with a rather sharp point at the top. As might be expected, the critical temperature and expansion to that temperature were not significantly affected by shape; but the softening temperature and expansion of the slender specimen were 595°C and 79 microns, while similar values for the stocky specimen were 610°C and 91 microns, respectively. Hence under these conditions it is evident that one might obtain a difference of 15°C in softening temperature and 12 microns in expansion, depending upon the shape of the specimens used. No such extreme differences in shape existed between the specimens used in determining the data presented in table 1, but there was certainly some differences and these would account to some extent for such irregularities as occur in the softening temperatures and corresponding expansions. As a matter of fact, the unavoidable differences in shape of the points of the specimen which are in contact with the interferometer plates have ordinarily more significance than the shape of the body of the specimen and it is probably the relatively rapid flattening of these points during the first test which causes a portion of the differences between first and second tests.

Comparison of the data on the soda-silica glasses reported in this paper with that of Turner and Winks[5] shows certain differences. For instance, their data on any one glass plot as a comparatively straight line up to the critical temperature, while the expansion values obtained at different temperatures in the present work plot more definitely concave upward. Also, their expansions for the lower temperature ranges are somewhat (approximately 2 microns) higher, although their softening temperatures (called annealing temperatures, A_t) and the expansions to these temperatures are somewhat lower than those obtained in the present case. Their softening temperatures, for example, conform reasonably well to a straight line about 7°C lower than curve A in figure 1. Their temperatures, designated by "C_t," are also lower than the critical temperatures reported in this paper and do not agree with them except in a general way.

These differences are not surprising when one considers that the data were obtained by two distinctly different methods of measurement which involved the use of specimens of decidedly different length (5mm as compared with 100 mm used by Turner and Winks); also, differences in the size of furnaces used and the consequent difficulty of obtaining uniform and reproducible temperature distribution should not be overlooked. It is thought that expansion measurements made by the interferometer method are very satisfactory for obtaining comparative data, because small samples can be used and also because no standard material of known thermal expansion is necessary for calibrating the apparatus.

Annealing Range. The proper annealing of glass is a problem which confronts every glass manufacturer and much has been written on the subject. The most noteworthy contribution is that by Adams and Williamson,[6] who point out the desirability of using different annealing temperatures for the same kind of glass, the actual temperatures used being dependent on the thickness of the piece to be annealed.

The annealing range for most commercial glassware

[*Concluded on page* 65]

CONCERNING FROSTING TROUBLES

IT IS a fault of many frosting departments that they do not adopt a systematic procedure and follow it religiously. Admitting this, and understanding the fundamentals of the frosting process, it is not surprising that many plants encounter a great amount of trouble which they are unable to diagnose correctly as it develops.

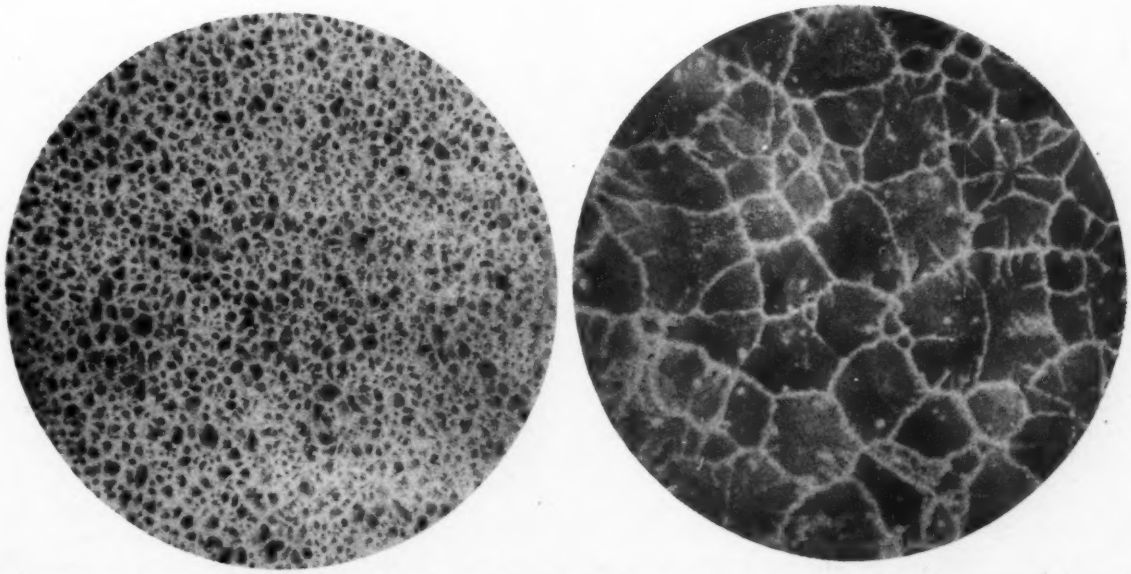
Several theories have been advanced to explain the process of frosting, or matt etching. The first theory assumes that the glass has a cryptocrystalline structure and that the etching process depends upon the same principle utilized in developing the crystalline structure of metals. The second theory holds that the matt etching results from the deposition of a crystalline or amorphous precipitate on the glass surface during the frosting period. The third theory holds that the crystalline appearing areas consist of amorphous glass. During the frosting of the glass surface, crystals of silico fluorides are formed and those crystals that form in contact with the glass surface protect the glass areas beneath them from further attack. Of these three theories, only the latter (termed the protection theory) has been completely confirmed and is generally accepted.

The development of the matt etch through protection of the surface in a bath of average composition, such as is described below, proceeds as follows: When the ware is immersed in the bath, a uniform solution of the surface first takes place. This solution of the surface lasts for a few seconds, after which a seeding of the surface with ammonium silico-fluoride crystals starts. At first these crystals are extremely small in size and are distributed at random over the surface. The crystals grow laterally very rapidly and following immersion for a period of about sixty seconds the entire glass surface becomes protected by interlocking and interfering crystals. Continued immersion to about three minutes has no apparent effect upon the general appearance of the crystals. After three minutes, however, the crystals appear to be cracking. And if the immersion period is continued, the crystal patterns will be entirely broken up. Glass removed from the bath between the one and three minute period will be smooth to the touch and satin-like in appearance. Glass removed after the three minute period has a "feel" like sand paper and is dense white in appearance. The former type of matt etch is the type desired for the majority of frosted containers.

As most container glasses are of the same general composition and the type of matt etch desired is usually the same (the so called satin finish), the frosting solutions used by the various frosting departments are all built around the same general formula. The following may be considered as average:

	Per cent by weight
Hydrofluoric acid (60%)	40
Ammonium bifluoride (32% HF) ...	30
Ammonium carbonate (28% NH_3) ..	10
Sodium carbonate (anhyd.)	5
Water	15

The above formula will develop a particular type of matt on a glass of a certain, definite composition. Any variation from the formula will result in a different etch. If the matt etch is to be kept of constant type, careful attention must be given to the purity of the materials and to the accurate weighing and mixing of the batch. For



Photomicrographs of frosted glass surfaces. The one on the left has a good satin finish, while the bath for the other contained an excess of ammonium carbonate.

example, in making up a bath from the above formula, if the alkaline material added was insufficient to reduce the acid content to the desired concentration, the solution and seeding of the glass surface would then be very rapid, and the resulting matt etch would show very small crystal patterns, be denser in color and duller to the touch than a glass surface frosted in the correctly proportioned bath.

If an excess of ammonium carbonate be added, the acid concentration would be lowered and the ammonium fluoride concentration increased. The result would be to slow down the solution and seeding of the surface. The resulting etch would then be glossy, show large crystal patterns and require a longer period of immersion. In addition to lowering the acid concentration an excess of sodium carbonate would also increase the viscosity of the solution by precipitating sodium fluoride. The crystal patterns would be slightly smaller and the appearance still satin-like, but the immersion time would be lengthened.

All of the above variations from the type formula actually occur in practice and are responsible for a part of the frosting department's troubles. They are due to careless mixing of the materials, careless weighing of the materials, and to the use of impure or old chemicals. Mixing and weighing errors can be controlled by responsible supervision, while the purity of the chemicals can be controlled by chemical analysis and proper storage.

Even though proper attention is given to the bath and to its composition, poorly frosted ware may still result. In most cases it will be found that details in the frosting operation have been slighted, or that the glassware is at fault. Errors in the frosting operation will be discussed first.

In discussing the protection theory it was shown that the time element is all-important. If the ware is removed from the bath before the protective action is completed, or if it is allowed to stay in the bath for a period longer than is actually required to completely protect the surface, a poor or unsatisfactory matt etch will result. A good method for preventing this is to determine the frosting time on the bath before starting the run and then to control the immersion period of each tray by a time clock.

A commercial bath usually contains a variable amount of precipitated material which is composed of insoluble alkali and silico-fluorides. Also in some baths inert material, such as barium sulphate or wood flour, is intentionally added. This sludge influences the viscosity of the bath and if it is in various stages of suspension, will cause variable viscosities throughout the bath. For a satisfactory etch, the bath should be so well mixed as to insure an evenly distributed sludge and should be kept in this state throughout the frosting period. This may be accomplished by stirring the bath before each immersion and by keeping the ware in gentle motion while frosting.

As was shown when discussing the protection theory, the first effect of the bath on the glass is the solution of the glass surface. If for any reason the rate of solution of the surface is not uniform over every part of the surface, some of the surface areas will seed more slowly than others. When removed from the bath these parts will show a different etch pattern and the ware will appear smeary or streaky. Glass surfaces that are greasy, weathered or cordy will react in this manner and will produce an unsatisfactry matt etch. Every precaution must be taken to prevent the ware from getting in this condition. Ware to be frosted should be made with as little "dope" on the moulds as possible and care should be taken to prevent the picking up of grease and finger marks during the packing and handling operations. If it is not possible to frost the ware immediately it should be stored in such a manner that the surface will not become contaminated by grease, dust or weathering. Unfrosted ware should not be allowed to stand in the frosting room for any length of time. If it is necessary to frost dirty ware, it should be first washed in a weak solution of hydrofluoric acid followed by a short drain. Washing in water is not recommended, as the water carried on the surface of the ware, even after draining for a few minutes, is sufficient to unbalance the bath and decrease its acid concentration in a few hours.

After the ware is removed from the frosting solution it is rinsed in cold water and then in hot water. Both waters should be changed rapidly enough to prevent too high an acid concentration. Neutralizing baths such as sodium carbonate solutions are not recommended, as the ware may dry with a white film.

LONDON SECTION MEETS

The London Section of the Society of Glass Technology held a meeting March 7, at Messrs. Holophane Ltd. The program was specially arranged for the benefit of thermometer manufacturers, a number of whom are members of the Section. J. G. Durham, long experienced in testing thermometers at the National Physical Laboratory, gave a most interesting talk, illustrated with lantern slides, dealing with the testing methods employed at the laboratory. A general discussion followed.

On April 4, the Section visited the works of James Powell and Sons (Whitefriars) Ltd. The program of future activities includes the Annual Dinner of the Society, which will be held at the Trocadero Restaurant, Wednesday, May 16, and a visit to Cambridge on July 7.

HONOR TO SAMUEL BERRY

What is undoubtedly the record for continuous employment in the service of one company was celebrated March 2, when the Whittall-Tatum Company tendered a dinner in honor of plant superintendent Samuel Berry. Mr. Berry had been with the company just seventy-one and a half years to the day on that occasion. Starting as a tending boy on September 2, 1860, he successively was promoted to gatherer, apprentice and journeyman glass blower, and finally superintendent of the big Millville factory.

Today Mr. Berry at 84 enjoys the best of health. In fact, the business of glass making has agreed with him so thoroughly that he has never had a doctor at his house in all the seventy and more years he has been with the company and for the past 18 years has never lost a single day's work on account of illness.

DAIRIES ADOPT BOTTLE TESTS

Precedents Being Established May Hold Serious Consequences for the Glass Container Industry

FOR years, manufacturers who package their products in glass containers have been asking the glass industry for tests that will indicate the degree of serviceability of their containers. These the glass industry has been unable to provide. Glass is too complex a material for its behavior to be easily predictable by such comparatively simple devices as are used in evaluating cans, paper boxes, and other types of containers.

But the user, the customer, knows nothing of the technical difficulties involved in developing reliable tests. Apparently he either believes that the glass industry is evading the issue; or else he is indifferent to the difficulties and is interested only in results. To him glass is just a type of container material. He wants a yardstick to apply to his glassware—and if the glass industry wont provide one, he is going to make one of his own.

A very important case in point is that of the Chicago Milk Dealers Bottle Exchange. Today it is testing practically every carload of milk bottles that is being shipped into the greater Chicago bottling area.

This fact of itself is of sufficient importance to warrant the consideration of milk bottle manufacturers shipping to that territory. But such is the prestige of the Exchange that there can be no doubt all milk bottle exchanges and all associations of milk bottlers all over the country will sooner or later follow suit. From milk, it is confidently predicted by those following the situation, the tests will spread to other container users—one of the largest drug manufacturers in New York City already has done so in part. From methods of testing to a purchasing specification is only a step. The Chicago situation, therefore concerns the entire glass container industry.

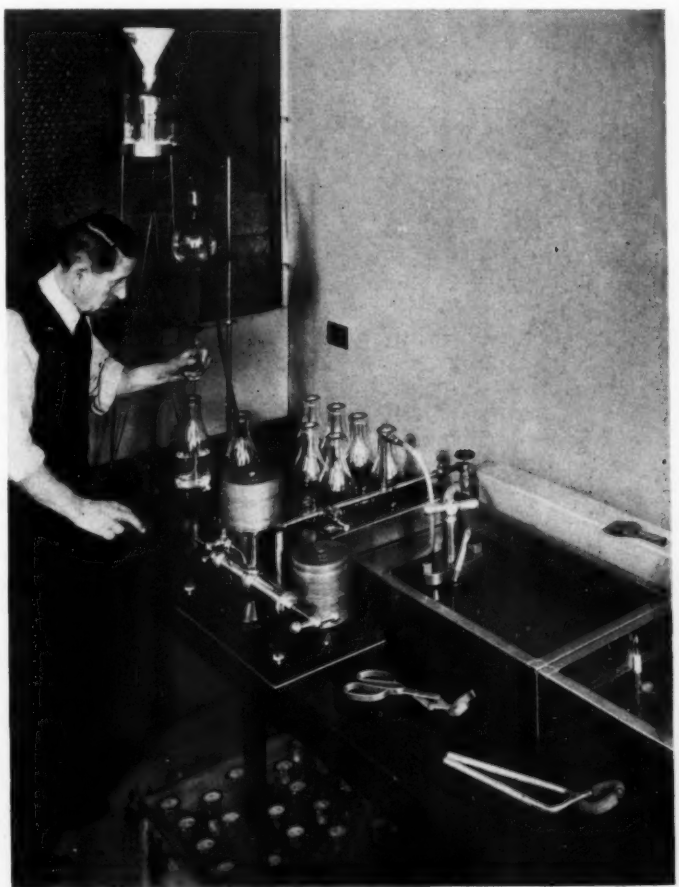
The paragraphs that follow outline the tests and the method of testing used at Chicago Milk Dealers Bottlers Exchange. It is suggested that a critical attitude to the tests themselves, however much the situation seems to warrant it, is perhaps less important to the glass industry than the fact that an outside agency, in no way connected with glass making, is imposing these tests on the industry. The glass industry cannot afford to risk the consequences either of the testing methods themselves or of the principle they establish.

The Chicago Milk Dealers Bottle Exchange is a clearing house for lost and strayed milk bottles, which it sorts and returns to the rightful owners. Its members and affiliates represent practically all the bottled milk used in Chicago, and a good deal of the area within a 70 mile radius. During 1931 the Exchange handled 73 million bottles and its present average is about one-quarter million a day.

The Exchange does not test milk bottles once they have been used. In fact, it got into the testing business not much more than a year ago. Some member companies that were having trouble with breakage decided the facilities of the organization might be extended to advantage in this direction, and the work has been carried on ever since.

Every time a member receives a carload of bottles it selects a dozen at random and delivers them to Frank Appell at the Exchange—Mr. Appell, incidentally, has no scientific training in glass technology. He did, however, by way of preparation for his work, spend some time in a glass factory studying the manufacturing process. Mr. Reuter, manager of the Exchange, selected him for the job primarily because of his personal qualifications—he brings to his work a sincerity, impartiality, patience and thoroughness in detail. Before he became the official tester he worked in the plant.

Mr. Appell makes six tests in the following order: Distribution and Weight, Polariscope, Capacity, Hydrostatic pressure, Temperature shock, and Impact.



TESTING FOR CAPACITY

Center foreground shows apparatus used for hydrostatic pressure and Temperature Shock tests. Note construction of monel metal tanks.

Distribution and Weight.

An examination of the wall thickness is made with a special gauge which indicates the thickness but does not give any exact reading. At the present time no effort is being made to establish any definite tolerances for variations in wall thickness.

The observer does report uneven sides or shoulders, if in his opinion, the variation is excessive.

Polariscope.

The apparatus is of the usual type. Interestingly enough, the Exchange does not lay too much stress on this test and has found the results to be very erratic. Only when the bottles test poorly by the other tests, does the Exchange count heavily on the Polariscope. The one exception to this is the presence of cords.

Capacity.

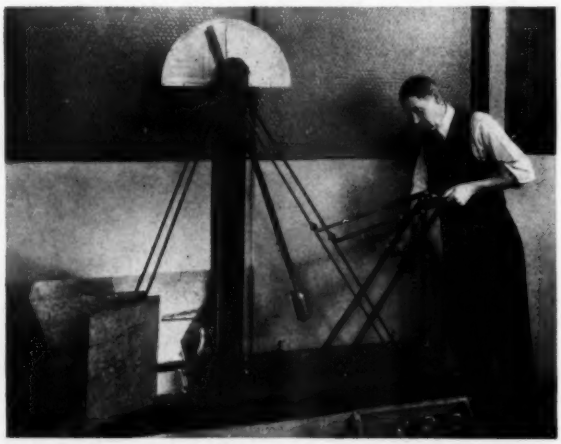
Usually not less than twelve bottles are selected at random from each shipment of new bottles. All bottles are measured for capacity by the use of a "Bureau of Standards" type of burette which delivers 33 fluid ounces, the last two ounces of which may be measured in sixteenths of an ounce. The measuring medium is water at a temperature of approximately 70° F. Bottles are considered acceptable that do not vary more than one-quarter of one fluid ounce from the thirty-two fluid ounce standard. The exchange is human enough to prefer having its bottles run close to the legal minimum rather than the maximum.

Hydrostatic pressure.

The hydrostatic test is made by clamping the bottle in a frame with the top against a rubber gasket. This gasket was taken from a "Milwaukee" milk bottle filler. The lower support acting against the bottom is bare metal. A standard gauge tester is employed to build up the pressure. The pressure is first brought up to 150 lbs. of pressure per square inch and if no failure occurs additional weight is added until the pressure is increased to 170 lbs. per square inch.

The results are reported as follows:

	BREAKING AT	
GRADE	150 LBS. SQ. IN.	170 LBS. SQ. IN.
Good	2 bottles	3 bottles
Fair	3 bottles	4 bottles
Poor	4 bottles	5 bottles



Making an impact test. Note the graduated scale indicating the swing of the pendulum beyond the break.

	Pol.	Cap.	170 lbs. sq. in. Hydro.	90° Temp.	in lbs. Impact	Break	Distribution
1	B	32	OK	OK	29.3	.....	Uneven base
2	B	32	OK	OK	...	.....	Even
3	B	32	Broke 150	.	...	Side & Bottom	Uneven sides
4	B	31 15/16	OK	OK	29.3	.....	Uneven Base
5	B	32 1/16	OK	OK	94.5	.....	Uneven Base
6	B	31 15/16	Broke 170	...	...	Shattered	Uneven sides
7	B	31 15/16	Broke 170	...	...	Shattered	Uneven sides
8	B	32	Broke 170	...	...	Side & Bottom	Even
9	B	31 14/16	OK	OK	157.6	.....	Even
10	B	31 13/16	Broke 170	.	...	Shattered	Even
11	B	32 1/16	Broke 170	OK	...	Lengthwise	Uneven sides
12	B	32 1/16	OK	OK	...	.....	Uneven base
	Com	OK	Poor	Good	Good		Poor

REMARKS: 75 per cent of bottles of poor distribution. Bottles breaking under low pressure. Demand improvement.

	Pol.	Cap.	170 lbs. sq. in. Hydro.	90° Temp.	in lbs. Impact	Break	Distribution
1	B	31 15/16	OK	OK	...		Even
2	B	31 14/16	"	"	...		Even
3	B	31 14/16	"	"	34.4		Even
4	B	31 15/16	"	"			Even
5	B	31 13/16	"	"	187		Even
6	B	31 15/16	"	"	...		Uneven shoulder
7	B	31 15/16	"	"	...		Even
8	B	31 15/16	"	"	49.2		Even
9	B	32	"	"	...		Even
10	B	32	"	"	...		Even
11	B	32	"	"	187.7		Even
12	B	32	"	"	...		Even
	Com	OK	100%	100%	100%		Good

REMARKS: 100 per cent Bottles.

	Pol.	Cap.	170 lbs. sq. in. Hydro.	90° Temp.	in lbs. Impact	Break	Distribution
1	Cord	32 1/16	Broke 170	...	...	Side	Even
2	"	32	Broke 150	...	...	Side	Even
3	"	32	Broke 150	...	...	Side & Bottom	Even
4	"	32	Broke 150	...	...	Side & Bottom	Even
5	"	32	Broke 170	OK	...	Bottom	Even
6	"	32	No test	OK	68.1	.....	Even
7	"	32	No test	Broke	...	Lengthwise	Even
8	"	32	No test	OK	34.4	.....	Even
9	"	32	Broke-170	OK	...	.....	Uneven side
10	B	32 1/16	OK	OK	...	.....	Even
11	Cord	32	No test	OK	34.4	.....	Uneven side & base
12	Cord	32	No test	OK	58.8	.....	Uneven side & base
	Poor	OK	Poor	Good	Good		Fair

REMARKS: This lot of bottles showing distinct cord under polariscope. Bottles breaking under low pressure. Plenty of room for improvement.

Above are exact copies of the data secured by the Exchange from three sets of tests, and typical of what it considers good, fair and poor bottles.

The location and type of break is recorded. If four bottles break the test may be discontinued and any bottles remaining after the shock and impact test put through the hydrostatic test.

Temperature Shock.

The bottles are subjected to a temperature change of 90°F by warming them for 3½ minutes in a hot water bath and then plunging them into water that is 90°F cooler than the hot water. The hot water is regulated at the start to a point 100°F warmer than the prevailing temperature of the cold tap water. The cooling of the hot water by the bottles brings the temperature down to approximately 90°F.

The bottles are removed from the hot water bath with rubber faced tongs, emptied and plunged bottom down into the cold water deep enough to permit cold water to flow into the bottle. If four bottles break the test may be stopped in order to have four left for impact test.

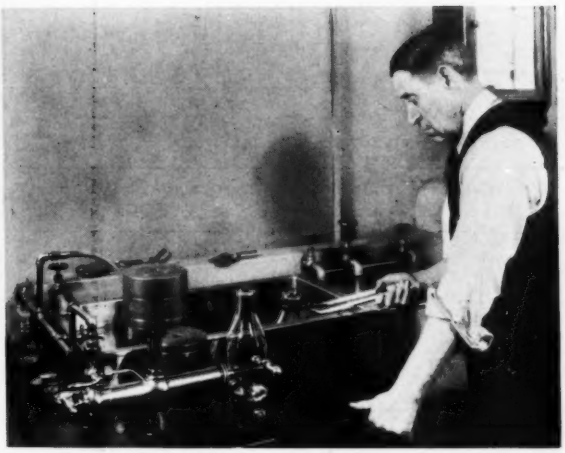
The results are reported as follows:

GRADE	BOTTLES BROKEN
Perfect	0
Good	2
Fair	3
Poor	4

Impact.

A blow is delivered at the side of the roll of the bottles by a pendulum-like hammer. The impact tester is cali-

E. Reuter, manager of the Exchange, using the gauge he devised for measuring the distribution of the glass.



Frank Appell, official tester, plunging a bottle in warm water after it had been chilled in water 90° cooler.

brated so that the energy required to break the bottle is indicated. The steel weight is capable of delivering approximately 187.7 inch pounds. A graduated scale located above the pendulum indicates, if the bottle breaks, the swing of the pendulum beyond the bottle. By reference to the calibration scale the actual energy expended in causing the failure is noted and recorded. The bottles are assumed to have passed the test of 32.7 inch pounds or greater are required to cause failure. Results of the impact test are erratic and are recognized as such.

Briefly, these are the tests to which the bottles are put. Results are recorded on a 5x8 card, of which some actual reproductions are given here. The cards, incidentally, are never available to the milk bottler but any glass manufacturer can inspect the tests on his own ware. The milk company receives a terse report from Mr. Appell couched in general phraseology, as: "Demand Improvement," or "100 Per Cent Bottles."

Mr. Reuter insists that his members are out to get not the cheapest but the best bottle. And, if necessary, they would be willing to pay more to get better bottles. The testing that has been going on for the better part of a year actually has resulted in better shipments.

The tests, as Mr. Reuter will be the first to admit, are frankly crude and imperfect; but he listens to suggestion and is quick to adopt refinements and improvements. As he puts it: "Glass container manufacturers may rightly quarrel with the tests themselves; but in its own meddling way the Exchange gets somewhere and knows it. Glass container manufacturers should not be so quick to criticize our methods but should adopt the more constructive attitude of helping us attain our objective. That objective, of course, is better bottles."

CERAMIC ACTIVITIES AT ALFRED

The student branch of the American Ceramic Society has been holding regular monthly meetings all winter. At the March meeting President W. Keith McAfee was the speaker. He gave a highly interesting address on the manufacture of sanitary ware and also gave the students some splendid advice on what the industry expects of them. About 120 attended this meeting. Other meetings this year were addressed most capably by Dr. A. V. Bleininger, and Mr. James Bailey.

The College was represented at the Cincinnati convention by six members of the faculty and ten seniors. The students here are completely sold on the benefits to be derived from attending the A.C.S. Convention.

The celebration this year in honor of St. Patrick, the patron saint of engineers, was an outstanding success. The parade consisted of twenty floats depicting the humorous side of college life at Alfred. The Open-House was attended by about 800 visitors from the western part of New York who saw all the laboratories in use with the students at their regular tasks under the direction of their instructors. The Corning Glass Works also put on a fascinating exhibit of glass blowing. The Tea Dansant in the Ceramic College was attended by 100 couples and the Formal St. Patrick Ball by 175 couples.

The graduating class this year consists of 19 seniors and 3 post-graduates in Glass Technology and General Ceramic Engineering. There will also be 18 graduates in Ceramic Art. This graduating class is noteworthy in that it graduates the first glass technologists.

Plans are underway for the Convention of the Ceramic Association of New York which will be held in the New Ceramic College Building on May 25th. Everyone interested in the work of this Association is invited to attend.

Announcement of the Summer Ceramic School which will be held at Alfred this summer is being mailed.

An exhibit is being prepared for display at the New York State Fair this year. The exhibit will consist of glass blowing, pottery throwing and jiggering, products of the ceramic companies of the State and educational charts and displays.

This Spring a short course for men from the industries will be initiated. It is tentatively scheduled for the week of May 20th. General courses in ceramics, special courses in petrography, glass technology, chemistry and mineralogy will be offered.

GLASS INDUSTRY

Devoted to Glass Technology, Engineering, Materials and Glass Factory Equipment and Operation

Published at 233 Broadway, New York, N. Y. by Cornelius O. Watney and John T. Ogden. G. W. Cooper, Editor

The New GLASS INDUSTRY

INTERIOR decorations reflect the character of the occupant. Beginning this issue THE GLASS INDUSTRY will go to its readers in an entirely new dress. Its reading pages are printed in a Bodoni type, selected because that particular face seems to reflect so admirably the industry we serve and the manner in which we will serve it—conservative in spirit yet in perfect harmony with the modern, progressive viewpoint. Our cover each month will be illustrated, now depicting some important news development or again with a subject purely artistic in character pertinent to glass making.

This change in THE GLASS INDUSTRY is more than superficial. A new management is at the helm: Cornelius O. Watney and John T. Ogden, known to many of our readers as the publishers of *The Glass Packer.* This new publishing direction will give the glass manufacturer a technical journal worthy of the great industry whose name the publication bears.

In the publication of scientific papers and semi-technical articles, the glass industry needs to have new standards established in this country. Although the research investigator is ably served by the scientific journals, there is at least a question whether or not papers relating purely to glass should not be cleared through a single channel and in that way made available to the entire industry. Nor is the foreign technical literature available to our own research workers. By selecting such articles from the foreign press as seem of particular interest to American investigators and by supplying summaries translated into the idiom of our own glasshouses, we believe still another service can be supplied that will be unique and of inestimable value.

There can be no doubt as to the need that exists to encourage the writing of semi-technical articles, and to promote the exchange of opinions and experiences concerning the everyday processes of glass making. This is almost entirely lacking in American commercial literature today. Nor should the publication of scientific and semi-technical literature be incompatible in the pages of an industrial journal; particularly in the glass industry, where the laboratory and production departments frequently parallel each other so closely as to actually lose their respective identities.

THE GLASS INDUSTRY has been particularly fortunate in having the cordial and active cooperation of many eminent glass technologists. With their help THE GLASS INDUSTRY pledges its utmost endeavors to build a publication truly representative of the glass industry.

Discharge This Obligation

THE president of the American Ceramic Society, W. Keith McAfee, has just issued a call for more members. Although the Society is more active today than at any time in its history, its revenues are falling behind and are no longer adequate to meet the demands placed upon them.

Mr. McAfee's appeal should meet with instant response from every glass manufacturer. The American Ceramic Society has done much to promote the advance of glass technology in the United States, and this research is vital to the progress of the industry.

Membership is therefore a duty. Discharge the debt by mailing your check for $25.00 to A.C.S. headquarters at once.

"They Don't Speak Our Language"

SOLUBILITY tests for glass, for many years the subject of much discussion among glass technologists, seem to have reached the stage where something is going to be done about them. It has been suggested that the Glass Division of the American Ceramic Society hold a symposium on the subject at its summer session. Whether or not a symposium will bring the problem any nearer a final solution depends a great deal upon the attitude of mind with which the conferees approach the matter, and if the Cincinnati discussion is any criterion the outlook here is not as promising as one might hope.

Reference to the literature of glass making shows there exist almost as many methods for testing solubility as there are glass factories. Some of these methods did not even originate within the industry. Some were devised by customers—users of glass—who desired a better grade of ware than was ordinarily available commercially. The latter, however well they understood the chemistry of their own products, could not be expected to know the technology of glass making.

The situation was further complicated by the fact that glass makers themselves found a need for solubility tests of an entirely different kind and intended for an entirely different purpose—weathering, or storage. These were developed by the chemists of the glass companies, individually, in their own laboratories, and served to correct purely local or internal problems incident to the company's manufacturing technique.

Still a third set of solubility tests arose from functional problems. The milk bottle, for example, required a glass that would permit the container to handle milk successfully; the boiler gauge needed glass of still another type, and so on.

Thus it is evident that solubility tests have sprung up in a somewhat haphazard fashion, many of them unrelated, and none of them standardized, and each one devised for an entirely different purpose. Consequently, whenever glass technologists meet to discuss the question they inevitably see the problem from the viewpoint of their particular company's experience. Is it any wonder, to borrow from a popular contemporary cartoonist, they "don't speak each other's language"?

However, in spite of every difficulty, there is no doubt but that the glass technologists eventually will come together in a common understanding of their problem. But in doing so they must not forget the consumer. He, too, must "speak our language." It is more than problematical whether the user of glass can be induced to discard his tests without sufficient unbiased evidence that the glass manufacturer's tests serve his purposes as well as those he has been using.

THE GREAT ENIGMA

By FRANK W. PRESTON

THIS note is a comment on the paper by J. T. Littleton, "Physical Processes Occurring in the Melting and Cooling of Glass", *J. Amer. Ceram. Soc.*, Vol. 17 (March, 1934) p. 43, and on the observations of G. W. Morey on the rate of release of strain at very low temperatures. Both of these gentlemen communicated their findings to the Cincinnati meeting of the Glass Division on February last, but Dr. Morey's paper is not yet (April 14) published.

I hope it may not be out of place to go once more over the history of the subject, in briefest outline, for the conundrum can best be understood at the present time by tracing the history of its development. This is not an attempt to appraise every individual's contribution to the establishment of the Great Enigma, and if some writers' names are not mentioned, I hope they will not feel slighted. We wish merely to give enough of the history to make the present position clear.

The term "annealing" is used in common by the steel and glass industries, which grew up together. As a workshop term, "annealing" means heating the steel of glass to a dull red and cooling it slowly. The article is then obtained in a "soft", "tough", and workable condition, as compared with the "hard" and "brittle" state resulting from rapid cooling. Both steel and glass can be "cut" when annealed, the one by a lathe or planer tool, the other by a diamond or glazier's wheel.

The processes are none the less physically different in steel and glass, however similar they may have appeared to workmen in the first instance. In the steel we get a recrystallization, the formation of new "ferrite" and "pearlite" grains, with a separation of the "temper carbon" and a breakdown of the solid-solution grains. In the glass, annealing does not throw out any ingredient from the solid solution. There are no crystals observable after annealing any more than there were before. The microscope gives no clue to what happened.

On the other hand a distinct change *is* recorded by the *polariscope*. The double-refraction or color-effects in the polariscope, usually conspicious in unannealed glass, disappear on annealing. And since double-refraction of this sort indicates mechanical strain in the glass, the annealing is said to "relieve the strains". This is not the same process at all as the annealing of steel.

By what process are the strains removed? Obviously by slight internal movements of the molecules or atoms of the glass, just as the steel is recrystallized by comparatively slight rearrangements of its atoms. What prevents the glass rearranging its molecules at room temperature? Obviously its exceeding *stiffness*.

Twyman seems to have been the first to identify this stiffness with *viscosity*. Viscosity is a precise scientific term while stiffness is mere vernacular. So Twyman set out to measure the viscosity over a range of temperatures not far from the annealing temperatures, and showed that it declined very rapidly as the temperature was raised. A rise of ten degrees centigrade halved the viscosity, and therefore presumably doubled the rate at which strain could disappear.

Since then viscosity has been measured by a number of observers over a wide range of temperatures and with great precision: a variety of methods have been used, and the results check very well together. At high temperatures, when the glass is really molten, there is no particular difficulty except the difficulty of handling the high temperatures. At lower temperatures, around the annealing range, the difficulties become much greater. A small variation or error in the temperature makes far more difference; the duration of the experiment must be greatly increased—it may take hours or days in place of minutes; the total displacement to be measured is very small; and finally uncertainty exists as to what we mean by viscosity when the displacement is so small.

Still worse is the difficulty of getting the glass into viscous equilibrium while the experiment is conducted. For as Stott and Tool and Lillie have shown, the glass does not reach an internal "constitution" or molecular arrangement appropriate to a low annealing temperature, for a very long time. This slowly-proceeding rearrangement of the works inside, results in small changes of refractive index and density, and in a very large change of apparent viscosity; always remembering that "viscosity" is a term which under these conditions of experimenting is a term subject to some scrutiny and question.

Twyman made the assumption that the rate of release of stress at any particular temperature, and therefore (presumably) at constant viscosity, was proportional to the stress then existing. This is the natural assumption. It is the famous compound interest law. We encounter it everywhere in the realm of nature. For instance, the rate of decay of radio-activity in a sample of radium is said to be proportional to the amount of activity in existence at the moment. So why shouldn't the rate of decay of strain in glass be proportional to the amount of strain in existence at any instant? Precedents had been set for such a belief by Maxwell and others.

The only difficulty is, that it wasn't so.

ADAMS and Williamson found that the decay of strain (measured as double refraction) was proportional not to the existing strain, but to the square of the existing strain. Thus when the strain had fallen to one-half, its initial value, the rate of strain-release had fallen not to one-half, but to one-quarter, of its original value. This means that strain is easily relieved when there is plenty of it, but it takes a long time to get rid of the last traces.

Now a law of this sort is unlike anything we encounter elsewhere in physics, and arouses much psychological opposition. It doesn't look right. It is an insult to our intelligence, after we have set the universe in order, to find a contemptible piece of glass acting in this fashion. There ought to be a law against it.

But Adams and Williamson's work was carefully done.

and if any confirmation were wanting, it was provided when Hampton endorsed their findings. Glass *did* act that way.

The present writer tried to make peace by pointing out that if Twyman's original view was correct, viz., that annealing of glass (rate of release strain) depended only on the viscosity and on the strain at any instant, then the Adams and Williamson law was mathematically inevitable. But mathematical inevitability did not dispose of the general uneasiness: if the mathematics was right, then the physics must be wrong. There must be something else involved besides the factors taken account of by Twyman.

BERGER in Germany adopted the attitude that annealing has nothing to do with viscous flow. This is starting at the beginning and denying *in toto* the Twyman concepts. To American minds it is probably none too clear what Berger does suppose annealing to be. It seems clear that strained glass is rendered unstrained by annealing; and that there is a rearrangement of the internal structure—a closer packing of the molecules. But Berger takes the attitude that this rearrangement is not a matter of viscous flow, that it is more akin to a recrystallization, as in the annealing of iron. Perhaps such a repacking could be effected in great measure by rotating various molecules *in situ*, without sliding them past each other as in viscous flow of the type used in measuring the viscosity of water, for instance.

In this country Berger's views, which probably are very inadequately presented above, have met with little approval. The objections have perhaps not been fully set forth in print, but perhaps they can be outlined:

We concede that in annealing there is a tightening of the internal structure as well as a release of stress. We concede for instance, that there is a deficiency of density in badly strained (badly annealed) glass which is vastly greater than the variations in density produced by mechanical strains in a well annealed piece, but this fact has been known for many years past and is in our eyes of much less importance than it is in Berger's.

We take the attitude that from a practical point of view, the reduction of stresses from several thousand pounds per square inch in badly annealed glass to virtual zero in well annealed glass, is vastly more important than an increase of refractive index of one unit in the third decimal place, or a corresponding increase of mechanical density. Those stresses loom large.

We know that at annealing temperatures, mechanically induced stresses of the magnitude of annealing stresses actually do cause viscous flow. Twyman really showed this at the outset. A lathe of glass sags and takes on "permanent set" when loaded heavily at the annealing temperatures. This also Hampton proved, and Bailey and Sharp determined "annealing constants" from externally applied loads, observing both release of stress and mechanical flow in the process. And in fact, all mechanical measurements of *viscosity* at annealing temperatures, such as those made by Lillie, depend for their very existence on flow being possible under stress.

If then externally applied loads are observed to produce viscous flow, we are unable to see how stresses arising from thermal origins can fail to produce flow.

We are therefore left with the conclusion that viscosity has something to do with the case, but that we are not satisfied that it is all.

Bailey showed that there must be some snag in the rate of release of stress being proportional to the square of the stress, since his mechanically loaded beams did not act that way. The double refraction observed in a bent beam when analyzed with a Babinet compensator shows a straight sloping line. Now if the rate of strain release is proportional to the square of the strain, the Babinet line should become curved during the releasing process. At first Bailey thought this is what did happen, but further careful experimenting convinced him it didn't, the line remaining perfectly straight, but the slope decreasing. In that case rate of strain release must be proportional to the strain, not to the square thereof. That is, the law is "exponential".

He also established the fact, that on second and third runs on the same specimen, the rate of stress release declined. The glass behaved as if its viscosity were increasing. The same piece of glass at the same temperature did not have the same viscosity. The longer it was kept, the stiffer it got. This is due, apparently, to the tightening of the internal structure, as observed by Tool and others, even in the absence of mechanical stress.

Lillie went to great pains to determine how far the viscosity did actually increase with time, and by mechanical measurements established a very large increase, and that it was necessary to wait weeks before anything approaching a final value was obtained.

Littleton, foreseeing that this increasing viscosity would have the effect of slowing down the strain-release in the later stages, when the annealing strains had already become small, surmised that if we could correct our annealing observations to allow for this varying viscosity, we should find that rate of stress-release was in fact exponential, the Adams and Williamson results being merely an empirical statement of what we observe, and useful for computing purposes, though misleading as a statement of scientific fact. He therefore determined the rate of stress release and the rate of viscosity increase at a steady annealing temperature, Lillie doing most of the experimental work.

THE actual experimental procedure is a little complicated by the fact that it was not a single temperature that was used, but during the first thirty or forty minutes the specimens were being brought up to temperature. However, as the test lasted 3000 minutes in one instance, 30 minutes at the start is not a serious fraction of the whole; in any case, the viscosity test (mechanical measurements) exactly paralleled the annealing test (optical measurements) in temperature schedule.

The results satisfied Lillie and Littleton that at any instant, the rate of strain release was in fact proportional to the existing strain. Their Fig. 6 is fairly conclusive on this point. The viscosity is increasing as the stress diminishes, and it is this that makes the Adams and Williamson law appear correct.

The conundrum now emerges. The Adams and Williamson law is in most cases not an *approximation*: it is extraordinarily accurate. It is much more accurate, in fact, than the exponential law derivable (as in Littleton's Fig. 6) when the variation in viscosity has been allowed for.

Let us assume, as Lillie tells me should be done, that the exponential law would be quite accurate if the experimental work (which is quite difficult) could be done with sufficient accuracy. It would still leave the central conundrum untouched: why is the Adams and Williamson law so extraordinarily accurate?

Apart from the original data of Adams and Williamson, of Hampton, Bailey and Sharp, and Lillie himself more recently, Morey has recently completed a rate-of-strain release test at low temperatures, extending over nearly two years. This is probably the most ambitious and most accurate experiment of its kind ever attempted, and shows that, after an initial period, the Adams and Williamson law is obeyed with the greatest fidelity.

Now if the Adams and Williamson law were only an approximation, we could dismiss it as being merely a convenient empirical result, useful in figuring annealing schedules. We could adopt the Bailey-Littleton law as representing the full physical significance of the problem. But when we find the Adams and Williamson law so very accurate, it seems inescapable that it has functional significance.

If both laws are rigorously correct, they are connected by the statement that during the annealing process, the viscosity at any point at any instant is inversely proportional to the stress there. Or, as "fluidity" is the reciprocal of viscosity, *the fluidity of the glass is proportional to the stress.*

This puts us in a dilemma. When finally we have annealed the glass perfectly, we have no stress, and therefore no fluidity. That is, *the glass has an infinite viscosity when perfectly annealed.* Such a view has nowhere received any credence to date. It has always been believed that the glass approaches a limiting, finite, viscosity at any temperature, and in fact Lillie himself has shown very convincing evidence that this is the case.

As things stand at present, then, we are forced to conclude either that the Adams and Williamson law is not correct at low stresses, or that the Bailey-Littleton one is not correct at low stresses. At the moment a comparison of Morey's latest graph and Littleton's Figure 6 leads us to believe that the Adams and Williamson law is the more correct.

Clearly the last word has not yet been said on the subject, and any explanation that pretends to be complete must give a rational explanation of the accuracy of the Adams and Williamson law. Until this is done, the evidence adduced by Bailey and Sharp and Lillie and Littleton that the real law is exponential, even if admitted, will not be more than a thickening of the plot.

ALFRED UNIVERSITY SUMMER CERAMIC SCHOOL

The New York State College of Ceramics is sponsoring a ceramic summer school which will be held at Alfred University this summer from July 2nd to August 10th. It is believed that there is enough of a demand in this country for ceramic instruction during the summer to support one summer school. High school teachers of ceramic art, technical and non-technical workers from the ceramic industries, students from other institutions having work to make up and graduates not employed will find in this summer school opportunities to obtain instruction in regular and special courses in ceramic art, technology, and engineering.

Attention is called to the fact that the summers at Alfred are cool and pleasant in every way. The high altitude precludes hot weather. Golf courses are available at nearby towns as are also facilities for swimming, horseback riding, and tennis. Living expenses are very moderate.

The faculty consists of Dr. C. F. Binns, Dr. S. R. Scholes, Prof. C. R. Amberg, Prof. M. J. Rice, Prof. R. M. Campbell, Prof. C. W. Merritt, and Prof. H. S. Nash of the University of Cincinnati.

The courses of instruction include lectures and laboratory in the following subjects:

General Ceramic Technology, Whitewares, Enamels, Petrography, X-Ray Analysis, Raw Materials for Glass, Glass Working and Melting Processes, General Design and Pottery Production, Jewelry and Metal Work and Weaving.

In addition to the ceramic courses listed above, the Liberal Arts College of Alfred University offers courses in Biology, Physiology, Inorganic, Organic and Analytical Chemistry, Drafting, Economics, Education, English, History, French, German, Mathematics, Physics, Spanish, and Psychology.

Detailed information may be obtained by addressing Waldo A. Titsworth, Director of the Summer School, Alfred, New York.

NEW PUBLICATIONS

GLASS CONTAINERS FOR COTTAGE CHEESE AND SOUR CREAM. Simplified Practice Recommendation R 148-33. Division of Simplified Practice, National Bureau of Standards. Available from Superintendent of Documents, Government Printing Office, Washington, D. C. 5 cents.

The results of a survey of cottage cheese and sour cream containers are shown by recommendation for their standardization. Dimensions and tolerances for the base diameter, height of bottle, height of finish, cap seat diameter, and over-all diameter of finish of roll of standardized 8, 12 and 16 oz. glass containers for cottage cheese and sour cream are given.

A SYMPOSIUM ON CAST IRON. The American Society for Testing Materials, 260 South Broad Street, Philadelphia, and the American Foundrymen's Association, 222 W. Adams St., Chicago. Cloth covers $1.25; heavy paper covers $1.00.

Data on the composition, metallurgy, properties, and applications of many grades of cast iron are given.

COST AND PRODUCTION HANDBOOK. Edited by L. P. Alford. The Ronald Press, New York. Flexible binding, 1600 pages. $7.50.

Covers budgets, cost analysis, depreciation, handling materials, labor, machinery, operating charts, purchasing, standardization, and time keeping.

FEBRUARY EXPORTS OF GLASS

A preliminary statement of the exports of glass products from the United States has been issued for the month of February by the Department of Commerce. Those products showing the greatest volume are listed in the table below.

Exports of other glass products which are not included in the table and which consist largely of cut or engraved table ware, lamp chimney and lantern globes, chemical glass ware, and miscellaneous glass other than electrical total $97,119. Canada was by far the largest foreign recipient of cut table ware, with $1,298. British India took nearly 25 per cent of the lamp chimneys and lantern globes, with $1,108. Of chemical ware, Canada took half, or $5,144 and China $1,946. Among the miscellaneous items, Canada again was our best customer with $59,499. Mexico, Cuba and Australia were also prominent in this group.

A condensed summary of exports for the four largest export groups follows:

	Plate Glass (unsilvered)		Window and Other Plate Glass		Glass Containers	Table Glassware Plain
	Sq. Ft.	$	Lbs.	$	$	$
Denmark	....	....	7,200	2,227	63	....
Netherlands	6,095	2,624	....	....	....	....
United Kingdom	....	....	....	....	1,730	4
Canada	208,140	68,117	22,192	4,606	29,087	14,087
Nicaragua	....	....	1,079	135	63	91
Panama	....	....	514	103	2,832	508
Salvador	....	....	....	....	1,684	....
Mexico	32,680	10,863	1,397	402	4,223	3,745
Jamaica	....	....	....	....	1,095	109
Cuba	....	....	524	175	16,485	5,856
Dominican Republic	....	....	3,022	377	766	822
Neth. West Indies	1,300	285	....	....	54	442
Virgin Is. of U. S.	....	....	2,114	82	212	189
Argentina	12,691	4,470	405	248	2,230	....
Brazil	....	....	....	....	1,363	628
Chile	....	....	1,918	286	55	200
Colombia	....	....	4,733	430	3,536	70
Peru	1,162	429	....	....	1,836	1,780
China	....	....	....	....	1,667	483
Japan	33,519	11,112	832	98	125	....
Philippine Is.	19,650	6,055	....	....	1,500	1,341
Australia	112,094	38,445	....	....	499	54
New Zealand	1,033	367	....	....	453	434
Un. of So. Africa	....	....	3,620	1,750	3,005	1,731
Egypt	....	....	....	....	2,128	....
All other Countries	249	338	1,540	320	5,472	3,082
Total foreign	428,613	143,105	51,090	11,239	82,163	35,656
Alaska	....	....	....	....	483	....
Hawaii	13,651	5,198	24,026	1,428	5,456	1,474
Porto Rico	2,104	625	48,305	2,683	16,455	1,185

MARCH PLATE GLASS PRODUCTION

The production of polished plate glass by the member companies of the Plate Glass Manufacturers of America as reported by Secretary P. A. Hughes, for the month of March 1934 was 9,926,859 sq. ft., as compared to 7,441,278 sq. ft. produced by the same companies in the preceding month, February 1934, and 4,881,322 sq. ft. produced by the Association members in the corresponding month last year, March 1933.

This makes a total production of 24,975,332 sq. ft. by these companies during the first quarter of 1934, as compared to 16,309,780 sq. ft. produced in the last quarter of 1933 and 16,024,878 sq. ft. produced in the first quarter of 1933.

J. J. Greene has been appointed administration member of the code authority for the glass container industry, succeeding Malcolm Muir, resigned. Mr. Greene is vice president of Johns-Manville, Inc., New York.

BELIEVES EDITORIAL WAS MISLEADING

Editor, GLASS INDUSTRY:

After giving some thought to your editorial in your March 1934 issue on "Glass Division Papers," I am sure that any reader of this who was not present at the Cincinnati meeting will form an erroneous impression of the general quality of the papers presented. Your first paragraph is complimentary to some of the papers, but even this leads to the conclusion that the average quality of the program was below par. I feel this does not represent the sentiment of those present, for I myself and all those I talked with expressed themselves as very highly pleased with the character of the papers in general. I think you have over emphasized the criticism of the papers so that one would conclude that this was the predominant characteristic of the meeting. No doubt this was not your intent.

As a matter of fact I only recall one paper that was criticized from the floor by one man, and I did hear many others state that they had gotten some useful information from this particular paper.

I agree with you that all papers should be in the hands of the program committee at least thirty days prior to the meeting and preferably sixty days but so far that has not been practical. The program committee has a difficult job in getting up a program and while of course it exercises considerable supervision over the material presented it is unable to go as far as we would like to have it go.

You may publish this letter if you so desire. At any rate I hope you will correct the impression your editorial made, which impression I am sure is far from the one you intended to convey.

J. T. Littleton
Chief, Physical Laboratory
Corning Glass Works

The Board of Trustees of the American Ceramic Society will meet in Buffalo May 4 for the purpose of selecting a city for holding the 1935 annual meeting.

FLEXIBLE GLASS

A new plate glass is being introduced by the Triplex Glass Co., Birmingham, England, that is claimed to be unbreakable. This glass is flexible to a marked degree and will stand great pressure. On a sheet a yard or so long, raised on two supports, two men can stand; the only effect being that the glass curves slightly, resuming its normal straightness immediately the weight is removed.

The Board of Trade has sanctioned the use of this glass, in ½ inch thickness, for ship's portholes, instead of the normal thickness of one inch. Composite sheets of the glass have been subjected to shots from rifles and revolvers, and while in some cases the outer sheet may be dented, the mass remains intact.

Don't forget that May is the best month in 1934 to join the American Ceramic Society. Application blanks should be mailed to Ross C. Purdy, general secretary, 2525 North High Street, Columbus, O. The fee is $10.00 for personal membership and $25.00 for corporations.

ON THE FORMATION OF SODIUM SULPHATE IN OIL FIRED GLASS FURNACES

By W. R. LESTER
Maryland Glass Corporation

THE effect of fuels containing excessive amounts of sulphur on glass melted in tank furnaces has been recently described by Turner.[1] The following is a further contribution to the general subject:

For the past several years a very heavy fuel oil (11° to 14° Baume) has been used for glass melting, while a light fuel oil (28° to 32° Baume) has been used for heating the feeders and lehrs. The sulphur content of the heavy oil runs on the average about 1.75 per cent but at times it has reached values between 2 and 3 per cent. The light oil runs fairly constant around 0.50 per cent sulphur. The glass batch used contains only a small amount of saltcake (5 lbs. to 1000 lbs. of sand).

As Turner has shown, any sodium sulphate formed by the reaction between the products of combustion and the sodium oxide vapor about the glass, will condense in the cooler portions of the furnace and form the well known "salt-water". Only on one occasion, however, have we actually experienced this phenomena. Following a twenty-four hour shutdown sufficient "salt-water" collected in two adjacent feeders to necessitate their being blocked off and the "salt-water" removed. The rarity of this phenomena with a fuel as high in sulphur content as the above is due no doubt, entirely to the practice of keeping a high and constant temperature in all parts of the furnace and feeders.

However, the appearance of "salt-water" is less serious than is the action of the sodium sulphate on the refractories and on the checkers, as well as the checker slags that are formed from it. The part that this sodium sulphate plays in corrosion and slagging is generally lost sight of due to the many other factors that overshadow its effect.

An instance where the sodium sulphate, formed from the sulphur in the fuel, attacked the refractories came to our attention a few years ago. At the time considerable difficulty was being experienced in locating the cause of large black and brown drops of glass that appeared in the ware. On investigating all possible causes, these drops were found on the overhanging refractory blocks in the cooler parts of the tanks. Analysis of both the glaze and the drops from these blocks showed the presence of about 1 per cent sodium sulphate. That sodium sulphate was actually present in the atmosphere at these points was proved by the analysis of condensed material taken from alongside of tank "sting-outs" (Table I). Recurrence of this dripping was prevented by the use of a more refractory type block for these positions.

Analysis of typical slags taken from the checker work and from the flues are shown in Table II. The presence of such a large quantity of sodium sulphate causes these slags to severely corrode the checker brick at the hottest zones with the result that the checkers in the cooler zones become considerably clogged.

TABLE I Analysis of Condensed Material

	Peep Hole	Feeder Stack
	%	%
SiO_2	8.47	2.00
R_2O_3	6.00	2.62
CaO	2.92	5.00
MgO	2.71	2.46
SO_3 as Na_2SO_4	80.07	86.50
Total	100.17	98.58

TABLE II Analysis of Checker Slags and Dust

	Slag*	Slag#	Dust from Flue Floor
	%	%	%
SiO_2	15.68	15.56	17.90
R_2O_3	9.14	10.30	4.20
CaO	22.32	5.82	11.40
MgO	11.76	2.45	7.50
SO_3 as Na_2SO_4	47.70	75.40	56.13

* Batch hand fed to furnace.
\# Batch mechanically fed to furnace.

It is well known that oil firing is much more severe on both the tank refractories and the checker brick than is gas firing. The higher sulphur content of the oil may be a contributing factor when it is considered that a heavy oil such as is used by many plants will introduce into the furnace over 500 pounds of sulphur in twenty-four hours (based on 2,000 gal. of oil, having a sulphur content of 2 per cent) and that many corrosive products (SO_2,SO_3,H_2SO_4,Na_2SO_4, etc.) may be produced from the combustion of the sulphur, under glass furnace conditions.

[1]Note on the Formation of Sodium Sulphate in Glass Furnaces and of some Defects Arising Therefrom, W. E. S. Turner, (*J. Soc. Glass Tech.*, 1933, 17, 65, 22).

ST. LOUIS AUDITORIUM TAKES MANY FEET OF GLASS

Twenty thousand square feet of polished plate glass was used in the Auditorium. This glass was all furnished and installed by the Nurre Companies of this city, who also furnished the 395 copper-coated mirrors used in the dressing rooms of the Music Hall. This was one of the largest glazing jobs ever performed here and required the services of a crew of fifteen specially trained craftsmen to make the installation.

SELECTED SUMMARIES OF GERMAN TECHNICAL PAPERS

Editor's Note: In this department, GLASS INDUSTRY will publish each month translations of selected foreign technical literature on glass. At present, it is possible to review only the German writings, but the publishers plan to extend the scope of the Department as rapidly as circumstances permit to include other languages and nationalities.

ELECTRICAL GLASS MELTING

A series of articles now being published in *Glashutte*, by J. Horowitz "Electrically Heated Furnaces in the Glass Industry and Their Economy," treats the subject fully and historically. Illustrations from photographs indicate the surprising extent to which experiments along this line are being carried, in Europe.

Electricity has been applied to generate heat for melting, annealing, and decorating. Although attempts at electrical melting go back to 1880, it is only in recent years that accurate engineering data have shown the way to success. The installation of electric lehrs is regarded as simply a question of economy.

Fuel is regarded as accounting for from 20 to 30 per cent of the cost of glass manufacture. The author estimates that this outlay for fuel is divided, in bottle-factories, about as follows:

	Per cent
Melting	60
Annealing	11
Power generation	17
Auxiliary ovens and furnaces	6
Heating work-rooms and offices	6
	100

When electric melting furnaces are considered, the effect on glass quality, especially on color, of the material in the electrodes, enters the problem. Impurities in the carbon, and the reducing effect of carbon and carbon monoxide, become important. But it is stated that both Sauvageon and Raeder succeeded, by using very pure graphite electrodes, in producing glass free from defects.

Arc and resistance furnaces are mentioned as the general classes. Resistance furnaces may be heated indirectly by resistors; by using the glass itself as conductor; or by a combination of these means.

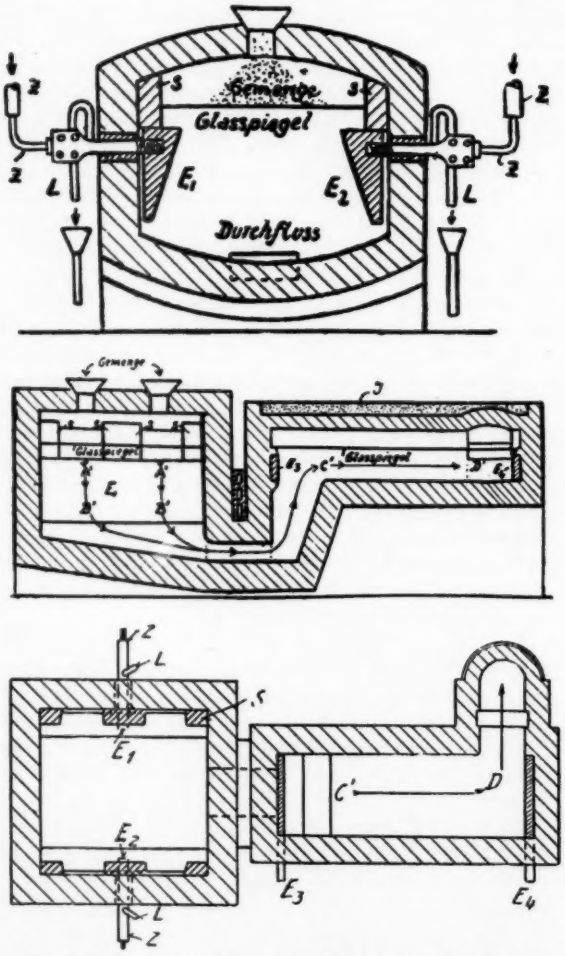
Glass appears to become a second-class or electrolytic conductor at 200°-300°C. Its conductivity increases rapidly with the temperature, doubling for about 200°C rise in temperature, reaching a specific value of 0.4 at 1400°C.

Electric furnaces for glass-melting have followed generally the design of flame-heated furnaces.

Many attempts have been made to apply the arc method of heating. One of the recent designs is that of Maetz of Sweden, who built a bridge-wall over which the arc played, so that no carbon particles, but only the radiated heat, could reach the glass. He melted glass with an expenditure of 1.3 to 2 Kwh per kilo. of product (about 1500 Kwh per ton).

Metallic resistors, even special alloys, cannot be used above 1300°C, but resistances built up of granular carbon have been utilized, notably by Bronn, who built an electrically heated closed pot, capacity 800 lb. and completed melts in about 30 hours with an expenditure of about 720 Kwh. The temperature was insufficient, and cracks developed in the pot.

The French glass manufacturer Sauvageon, in 1905, pioneered in glass-melting by direct use of the glass as



VIEWS OF RAEDER'S NEW ELECTRIC TANK

Z, Current leads. L, Water cooling. E_1-E_4, Electrodes. S, Block to retain electrodes. A^1-A^1, Melting space. B^1-B^1, Plaining space (1). C^1, Plaining space (2). D^1, Channel to feeder. J, Insulation.

resistor. His tank (for Fourcault sheet-glass) consisted of two relatively broad chambers in which the electrodes were inserted, connected by a narrow channel in which the heat-development was more intense, and where the melting process took place. The glass was not satisfactory for sheet, but good enough for green bottles. The energy consumed reached 4.8 Kwh per kilo.

Sauvageon attributed the bad glass to impure electrodes, and devised especially hard electric-furnace

graphite ones. Also, he provided auxiliary resistance of granular carbon over the furnace crown. The temperatures attained by this combination of arc and resistance-heating approached 1500°C, but the glass was still of poor quality and the power-consumption high. This type was abandoned in favor of an indirect-resistance design.

This furnace is described as having a semi-circular arch over an open pot, the carbon resistance lying upon the arch. Fair glass was produced, but the power required was very high—6 Kwh per kilo. Part of this lack of economy may be laid to the fact that the heat was transmitted entirely by radiation, and much of it fell elsewhere than upon the glass. Again, the intermittent operation of the pot occasioned much waste of heat.

It does not appear that a practical development of the Sauvageon furnace has yet been made. Perhaps, it is suggested, a larger furnace with more pots might show better efficiency.

Some degree of success rewarded the efforts at electrical melting, when the current used was reduced by applying direct-resistance heating to a tank furnace. Raeder, and also Cornelius, both in Sweden, achieved results at about the same time.

The essential conditions recited are: that the electrodes must not color the glass; they must either not be attacked or form no coloring oxide; if coloring results, the glass affected must not mix with the main body; if the electrodes are attacked, they must not make further contact with the corrosive portion of the batch; a batch must be employed, which will either not dissolve the electrode or not be colored by it; a quick-melting batch, which would be in contact with the electrodes so briefly as not to be affected; perhaps a combination of several of these favorable conditions.

Raeder made use of 3-phase-A.C., led into the glass through three pairs of electrodes, placed on opposite sides of three broad areas in a tank. A small throat led the glass from melting to refining chamber, where one pair of electrodes was placed.

The glass made good bottles, and the power-consumption of 200-250 Kw continuously on a tank rated at 5 tons daily amounted to 1.1-1.2 Kwh per kilo. A feature of Raeder's furnace seems to be the placement of the electrodes entirely beneath the glass-bath. The water-cooled leads reached the electrodes through a sort of "stuffing-box" in the side-walls. The electrodes were large, so as to reduce the current-density to 3 to 9 amperes per sq. cm. The purest obtainable graphite was used. (*To be continued.*)

THE ATTACK OF WATER UPON SODA-LIME-SILICA GLASSES

Keppeler and Thomas-Welzow of the Hanover *Technische Hochschule*, in the Mar. 15 number of *Keramische Rundschau*, complete a report of their work on solubility of glass.

They investigated both broken and formed surfaces, also compared the Standard and Keppeler methods, and worked out comparison factors.

The speed of solution of glass in water is found to be a parabolic function. That is, the square of the amount dissolved is proportional to the time. Reciprocally stated, the amount dissolved is as the square root of the time of attack. This law, apparently well-established by their data, provides a means for the extrapolation of results.

Another interesting result is the preponderance of soda over silica in the dissolved material, compared with the ratio in the glass tested. In the more soluble glasses, the dissolved alkali silicate could be given formulas like 4 $Na_2O{\cdot}SiO_2$, or even 5 $Na_2O{\cdot}SiO_2$. In the less soluble, acid glasses $Na_2O{\cdot}SiO_2$ and $Na_2O{\cdot}2\ SiO_2$ more nearly represented the dissolved silicate.

No conclusions as to constitution, or compounds present in the original glasses could be reached from the solubility tests

THE STATUS AND DEVELOPMENT OF SAFETY GLASSES

(Fritz Ohl, *Glastechn. Ber.* Feb. 1934)

A general discussion of safety glasses, placing the annual world-production between 50 and 100 million square feet, places America, England, and France in the leading positions. The usual organic materials for the inner layers are described.

As lines for research on improvement, the author suggests: greater speed of production; better endurance to extreme temperatures, especially cold; outer layers of toughened glass. He reports progress in the attempt to produce safety glass with layers capable of independent vibration, because of the softness of the organic bond.

Among the applications of safety glass are cited cylindrical and even spherical shapes, and bullet-proof or armor-glass. Toughened glass is urged as an additional means of strengthening such panes as railway-car windows.

Organic safety glasses are regarded as impractical because of the lack of a hard, polished surface; instability toward dust and weathering; and loss of transparency. The development of a completely unbreakable glass seems impossible.

THE COMPOSITION OF FOURCAULT GLASS

Dr. Ing. Joseph Muehlig[1] presents an account of the changes that have been found necessary in the composition of window glass to adapt it to the conditions necessary for machine drawing, especially the Fourcault Process.

Window glass to be blown by mouth by the classical "hand-process" had a very simple composition. Sand, salt-cake, and limestone were the batch ingredients, with a little arsenic and occasionally some manganese dioxide for decolorizing. Salt-cake came to be replaced by soda-ash, with improvement as to lessened attack on pots and blocks, but with slower melting. The composition of the glass was usually within these limits (with small amounts of minor oxides):

SiO_2	70-71%
CaO	15-13%
Na_2O	12-14%

This simple glass was completely satisfactory. Its viscosity could be varied to suit the workman by changes of temperature. The gatherer could load his pipe by

[1]Glastechnische Berichte, February, 1934.

making large or small gatherings at different times, to make up for inexact temperature control. The blower could regulate his operations in such a way that the increasing viscosity of the cooling ball or cylinder was an actual help. This adaptation of speed to temperatures and properties of the glass produced cylinders that were cut off and opened out into good sheets.

Assuming good materials, proper melting, and first-class workmanship, the finished sheet was satisfactory to the consumer in its freedom from visible defects; such as bad color, blisters, seeds, cords, waves, "music-lines" and wrinkles.

Other important criteria entered into consideration, such as resistance to dimming or clouding, resulting from attack by water and atmosphere in storage. The simple window-glass met this requirement very well, because its high lime and low soda content make it very insoluble. Solubility tests by the standard powder method would find for such a glass values of 30-40 mg. of dissolved material[2]—often less.

When Fourcault invented his drawing process and began experimenting, he used of course the glass at hand —the regular window glass composition above described. But he soon found difficulties. His process, or indeed any other mechanical drawing process, operates well only if a constant temperature is maintained at the debiteuse or in the fore-hearth, low enough so that the glass possesses a very high viscosity. But at such a temperature, the danger of crystallization or devitrification arises, especially with glasses like the old window glass, which devitrify readily at 1050-1100°C (1920-2010°F). The drawing temperatures are required to be lower than this range. Therefore these compositions were useless for Fourcault's work. He needed a glass of lower "liquidus" (upper limit of devitrifying), which must contain less lime and more alkali to obtain this result.

Mouth-blown window glass was made as "hard" as possible, because "soft" glasses are known to have poor resistance to weathering. But since the hard glass could not be drawn into sheets free from the crystals resulting from devitrification, Fourcault turned to a soft glass. In the early years of production by his process, the composition of the glass used resembled the following:

SiO_2	70-71%
Al_2O_3	0.2-0.4%
CaO	9-11%
Na_2O	18-16%

These changes reduced the liquidus about 200°F, or to a temperature below 1830° F.

The problem of production was solved. But the glass was notably poorer in its tendency toward clouding. Solubility tests would show 70-80 mg. of dissolved material, an amount not to be tolerated.

Another complication arose. The drawn sheets had remarkable flatness, and stacked together so closely in storage that they exerted a strong capillary action upon moisture condensed at their edges, drawing it into the thin spaces between the sheets. Here it attacked the glass, forming a caustic solution which exerted a corrosive action and destroyed the polish of the surfaces.

In view of the mechanical excellence of the sheets, this clouding effect was for a time accepted as a necessary evil. It was overcome to some extent by using sheets of paper between the panes, in packing. But eventually the dissatisfaction of the trade compelled some improvements.

Certain oxides, present in small quantities, change the physical properties of glass to a large extent. This is true of magnesia, which may be substituted in part for lime in a glass such as the hard window-glass of the past, with the result that the liquidus is lowered. Magnesia was next introduced into Fourcault glass, in compositions such as the following:

SiO_2	70-71%
Al_2O_3	0.2-0.4%
CaO	8-9%
MgO	4-3%
Na_2O	14.5-15.5%

The liquidus lies between 1740 and 1840°F. The solubility is 50 to 60 mg. Unfortunately, the replacement of lime by magnesia lowers the resistance of the glass slightly.

These glasses, albeit not as resistant as the old hard glass, were better by far than the soft glass of the Fourcault factories. Moreover, the plasticity of the magnesia glass was such that it improved the drawing factory of the process. This number (the cubic centimeters of glass drawn per minute per centimeter of breadth) rose from a 16 average with the soft glass to 21 with the new composition.

But the resistance of the glass was not satisfactory, and steps were taken to improve it by introducing alumina, an oxide whose effect in lessening the solubility of apparatus-glasses has long been recognized. The author presents curves to show the remarkable effect of alumina on solubility, as determined on a large number of window- and bottle-glass specimens. The additional 1 per cent Al_2O_3 reduces solubility about 40 per cent. The next 1 per cent is less than half as effective, and the maximum benefit is reached at between 3 and 4 per cent alumina. Further additions up to 17 per cent seem to have little additional effect.

Dolomite limestone is the best raw material for supplying magnesia (with lime); while feldspar is the accepted source of alumina, because it is already a silicate, and dissolves readily in the melt.

Alumina decreases the tendency toward devitrification, as well as the solubility. In the amount of 1 per cent replacing silica, it reaches its practical maximum. The goal attempted is now reached; the glass possesses lower liquidus, extraordinary workability, and good resistance. Its approximate analysis:

SiO_2	71%
Al_2O_3	1%
CaO	8.5%
MgO	3.5%
Na_2O	14.5-15.5%

Liquidus, 1740-1780°F; Solubility, 36-40 mg.

The resistance may well be further improved. Boric oxide failed to come up to expectations here, although it is a valuable aid to the melting of aluminous batches.

[2]This test appears to have been formulated by a committee of the Deutsche Glastechnische Gesellschaft as follows:

"Determination of solubility of glasses by Extraction of Glass Powder of specified grain size and weighing the residue on evaporation.

"About 10 (Sp. gr. x 4) grams of glass powder having a grain size 0.3-0.49 mm. to be washed with water or alcohol on the sieve and then leached by 100 cc. of boiling water for 5 hours under a reflux condenser in a 200-cc. conical flask, which must not lose weight perceptibly during the experiment and must be fully immersed in a boiling salt solution; 75 cc. of the filtrate to be evaporated, the residue dried to constant weight at 150°C. and the total for 100 cc. deduced."

BaO and K_2O seemed to influence the liquidus unfavorably.

Surprising results are reported when 1 per cent zinc oxide replaces I per cent lime. Not only is the resistance improved, but the liquidus is lowered. It is regarded as very unfortunate that zinc oxide is so expensive that it cannot be economically used, because it would be quite possible by a judicious introduction of ZnO, replacing CaO, to attain, if not excel, the resistance to weathering of the old hard glass.

Knowledge of specific physical properties as affected by each of these basic oxides added to glass in small amounts should enable us to make desired changes at will and with accuracy. More research will be necessary for a better understanding of glass. It is like steel, in that minor components influence its character very strongly. It seems safe to remark, that glass improves with complexity.

Speed of drawing is now held to be the prime requirement for a Fourcault glass. Now that matters of resistance and devitrification have been settled, attention is concentrated on speed. This depends upon viscosity, and of course viscosity increases as temperature is lowered. But there is a limit to the lowering of temperature, placed by the liquidus. Therefore the glass may not cool to the liquidus, or devitrification temperature, until it passes the debiteuse, where its rate of cooling becomes so rapid that crystals do not have time to form. The greater the viscosity of a glass at its liquidus, the better it is for production by the drawing process.

Some attention is paid to the improvement of the surface of drawn glass by exposure to flue gases. The belief is that SO_2 and probably also CO_2 react with alkali at the surface, and thereby remove some of it, leaving a thin layer relatively alkali-poor and therefore less soluble. This exposure to flue gases is especially feasible in the Colburn process; but also in the Fourcault, when the drawing space above the debiteuse is heated. This improved surface is not to be detected by the standard powder method, of course, but only by surface attack.

The writer recommends that more attention be paid to this surface treatment, also that both methods of resistance control be applied. He suggests also, as a further measure of preserving the polish of the surface, the use of sheets of paper impregnated with the salt of a very weak base and a strong acid. The theory set forth is, that the salt will act as a neutralizer, and prevent the formation of caustic when moisture accumulates between panes.

OWENS-ILLINOIS EARNINGS UP

At the Annual Meeting of Shareholders of Owens-Illinois Glass Company held at Toledo in April, it was announced that net earnings of the Company and wholly owned subsidiaries for the twelve months' period ended March 31, 1934 were $6,993,489.10, as compared with $2,466,008.15 for the corresponding period of 1933.

The Company is now employing more than 10,000 workers, which is by far the largest number in its history, and anticipates that the number will be still further increased by the demands for business this summer and the adoption of a shorter week.

THERMAL EXPANSIONS OF SOME SODA-LIME-SILICA GLASSES (*continued from page 50*)

lies between the critical and softening temperatures, but since the time required for annealing increases as the annealing temperature decreases, the optimum annealing temperature for any given piece will be as close to the softening temperature of the glass from which it is made as is consistent with the cooling rate that will be obtained in the lehr. Since the critical and softening temperatures of glasses of the soda-lime series may be read from figures 2 and 3, the approximate temperature ranges in which such glasses can be annealed may be readily estimated, but in this work no consideration has been given to the time required for annealing at various temperatures in the annealing range.[7]

Summary. The data and graphs in this paper, based on 19 soda-silica and 30 soda-lime-silica glasses, show the changes in thermal expansion, critical temperature, softening temperature, and annealing range of soda-lime-silica glasses with changes in composition in the range between approximately 12 and 50 per cent soda, O and 20 per cent lime and 50 and 80 per cent silica.

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*Publication approved by the director of the Bureau of Standards of the U. S. Department of Commerce.

[1]Faick, C. A., and Finn, A. N., The index of refraction of some soda-lime-silica glasses as a function of the composition, B. S. Jour. Research, vol. 6 (RP320), p. 993, June 1931; also Jour. Am. Cer. Soc., vol. 14, no. 7, p. 518, 1931.

[2]Glaze, F. W., Young, J. C., and Finn, A. N., The density of some soda-lime-silica glasses as a function of the composition, B. S. Jour. Research, vol. 9 (RP507), p. 799, Dec. 1932.

[3]B.S. Scientific Papers, vol. 16 (S393), p. 449, 1920. See also Merritt, G. E., B.S. Jour Research, vol. 10 (RP515), p. 59, 1933.

[4]For practical purposes, and also within the limits of accuracy of the data, it can be stated that the critical temperatures are approximately 93.5 per cent of the softening temperatures and that the expansions to the critical temperatures are approximately 88.5 per cent of the expansions to the softening temperatures. However, different conditions of annealing may materially change the latter figure.

[5]Jour. Soc. Glass Tech., vol. 14, p. 110, 1930.

[6]Jour. Frank. Institute, vol. 190, pp. 597-631 and 835-870, 1920.

[7]For information on time-temperature annealing effects and schedules, see reference cited in footnote 6. See also Tool, A. Q., and Valasek, J., B.S. Scientific Paper 358, 1919, and Finn, A. N., Jour. Am. Cer. Soc., vol. 9, no. 8, p. 493, 1926.

CLASSIFIED ADVERTISEMENTS

RESEARCH POSITION WANTED. A Ph. D. in Ceramic Chemistry desires research position in the glass industry. Age 27, married, excellent references, several publications. Now employed but desires change to research. Salary and location immaterial. Box 19, THE GLASS INDUSTRY.

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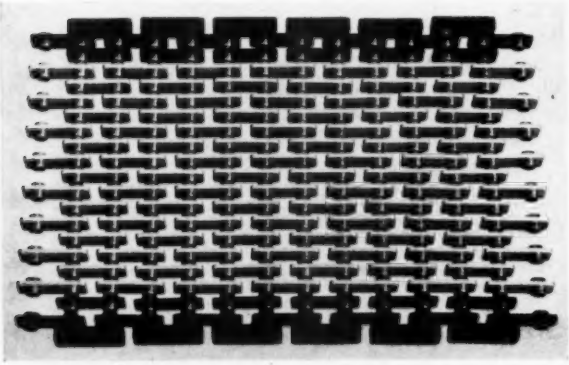
EQUIPMENT AND SUPPLIES

NEW CHAIN CONVEYOR DESIGNED FOR GLASS MANUFACTURING

A new conveyor chain, designed specially for use in glass plants to convey hot jars and bottles from mould to lehr, has just been announced by the Diamond Chain & Mfg. Company. Several years of research and actual factory usage accompanied the development of this special chain before it was announced to the industry. Of unique construction, the manufacturers lay emphasis upon two desirable features: Maximum openings for either



controlled or natural ventilation, and maximum continuity of an effectively smooth surface.

There is only one link plate for each link pressed centrally on two hardened steel bushings .200″ diameter by .211″ long. The plates are rectangular to give maximum continuity of surface. The pin plates as well as two outer rows of link plates are blued steel to accept the sliding wear on the steel tracks. The link plates in the central portion of the chain may be steel, aluminum alloy, or phosphor-bronze, depending upon the application. The latter two materials offer maximum assurance against checking, and may be used in the Diamond design without shortening the life of the chain—they do not carry the load against the sprocket teeth.

The steel bushings not only accept all the wear against the sprocket teeth, but they act as spacers, putting the link plates on .211″ centers. Their small diameter leaves an unusually large opening between joints, making it easier to control the temperature by air blasts from below. The assembled links are interwoven on hardened steel pins spaced for ½″ pitch sprocket teeth. Any desired width can be furnished.

DEMAND FOR SAND INCREASES DREDGING OPERATIONS

The sand dredging fleet of the Pittsburgh Plate Glass Company, the largest fleet operating in the Pittsburgh district, resumed operation Monday, April 9. The fleet includes the dredge "Pittsburgh", the steamer "Wacouta" and twelve attendant barges and scows. Dredging will be in the Sixth Pool in the Allegheny River and the product will be a very high grade sand used as the abrasive in the grinding operations at Ford City, Pa., where Plate Glass, Carrara Structural Glass and heavy Plate Glass are made; and at Creighton, Pa., where Plate Glass and Duplate automobile safety glass are produced.

The Allegheny River is closed for the four winter months so that during the coming eight months the dredging fleet must produce sufficient sand to supply current demands and build up a reserve for the four winter months. It is expected that during the coming eight months approximately 150,000 tons will have to be produced.

Due to the increase in the use of Duplate Saftey Plate Glass by motor car manufacturers and the growing demand for Plate and Structural Glass for new and modernized store fronts, the operating hours of the fleet will be greatly in excess of the schedule maintained during the past three or four years.

NEW LOW-PRICED TEST KILN

Accurate laboratory predetermination of the effects obtainable with new glass colors, and all similar experiments, can now be handled at any time, through a product just introduced—the Electrikiln. It makes the experimenter independent of plant production schedules in running tests, permits development work to continue even when the plant is down.

The Electrikiln is designed and manufactured by Harrop, and is distributed by the O. Hommel Company, Pittsburgh, sole agents. It may be plugged into any light socket, and is said to take less power and cost less to operate than the ordinary electric household iron. Weighing 27 pounds, and 9½″ x 10½″ x 15″ overall, it

is easily portable, may be carried around the plant, or taken home for running tests. The muffle firing space is 3½" x 3½" x 4". Temperature of from 1950 to 2000° are obtained.

The cabinet is sheet steel. Insulation is Celobrik—a new insulating and refractory material. Walls are packed with infusorial earth. Heating elements are Nichrome IV, and are easily and quickly removed for cleaning or replacement.

BUYS J. L. MOTT COMPANY

Harry A. Robinson, Morris Bldg., Philadelphia, has recently purchased the entire stock, patents, dies, molds, fixtures and good-will of the J. L. Mott Iron works at Trenton, N. J.

This purchase included the entire plant of approximately 1,000,000 square feet of buildings and 18 acres of ground, complete for the manufacture of bath tubs, lavoratories, plumbing supplies and pottery, and includes brass goods and everything incidental to the manufacture of all articles in this line.

Mr. Robinson reports that large foreign interests are now negotiating to acquire the plant, with the intention of continuing the manufacture of the J. L. Mott lines.

CATALOGS RECEIVED

The Apollo Metal Works, La Salle, Illinois are releasing a pamphlet and sample of Apollo Chrom Flex. This metal obtainable in crimped and striped patterns can be applied to wood moulding or plywood.

Link-Belt Company, Chicago have issued a new 1024 page catalog (600). The company refers to this as a handbook of practical information, engineering and dimensional, for the mechanical conveying and preparation of materials and transmission of power for the designer and buyer.

A new edition of U. S. Geological Survey Bulletin 679, "The microscopic determination of the nonopaque minerals", has just been published as Bulletin 848 obtainable from Supt. of Documents, Washington, D. C., for 20 cents. The new edition of 254 pages has been completely rewritten and the tables brought up to date by the introduction of about 500 new entries. About 250 new mineral species have been included and the data on the important mineral groups have been assembled in tables. This will therefore supercede the earlier edition.

The Parker Appliance Co., Cleveland, Ohio have issued a Bulletin 35—the first of a series covering all their line of production. This bulletin is a technical resume of their tube couplings for use in industrial plumbing. Other publications are engineering data, price lists and engineering charts for use in industrial designing.

The Brown Instrument Company, Philadelphia, Pa., have just published a new 32 page catalog featuring the Brown Resistance Thermometer for measuring temperatures from 300 to +1000°F. The Resistance Thermometers are available in indicating, recording and controlling types with improved features. They are completely described in Catalog No. 9001.

"*Insulation in the Glass Industry*". Johns-Manville Company, New York City. A 64 page catalog of the many J-M products, with information concerning the use of each product in the glass plant. Results of actual performance tests of J-M insulation in various glass plants are also included.

"*Index and Directory*". A complete listing of factories, manufacturing divisions, and products of the Pittsburgh Plate Glass Company, Pittsburgh, Pa.

"*The Louis Allis Messenger*". A bi-monthly magazine devoted to electric motors. May be obtained gratis from the Louis Allis Co., Milwaukee, Wisc.

HEADS NEW DIVISION OF OVERMYER MOULD COMPANY

On May 1st Kenneth R. Haley will assume charge of Tableware, Specialty and Lighting Glass Moulds, for the Overmyer Mould Co. at Winchester, Indiana. For several years, this company has been working to perfect the process of casting figured moulds, which is Mr. Haley's recognized specialty.

Mr. Haley is a son of the late Reuben Haley, who has been so well known in the glass industry for more than thirty-five years, and under whose skill the son was tutored from an early age. For the past seven years he has been designer and development engineer for the Phoenix Glass Co. His experience in designing, selling and making moulds for the trade makes it possible for him to contact the industry and fulfill their requirements with a thorough knowledge of good practice in design and mould building.

Overmyer Mould Company owns its own foundry—the only foundry in the country that produces iron exclusively for glass house moulds.

GENERAL ELECTRIC EARNINGS UP

The forty-second annual report of General Electric Company for the year 1933 shows profit available for dividends of $13,429,739, equivalent, after dividends of 6 per cent on special stock, to 38 cents per share on 28,845,927 shares of no par value common stock, compared with $14,404,110, or 41 cents per share, on the same number of shares in 1932. Dividends of 60 cents per share on the special stock and 40 cents per share on the common stock amounted to $14,112,633, resulting in a deficit from operations of $682,894, which was taken from surplus.

CATALOG OF FRENCH CERAMISTS

The 1933-1934 edition of the Annuaire Des Ceramistes Et Verriers De France contains 600 pages of data which has been revised and re-classified.

Divided into five groups, containing a general list by departments of all the French firms in these groups, the Annuaire des Ceramistes et Verriers de France also contains a complete list of the professional societies for ceramics, glass and related professions; a list of tariff experts for these industries; a list of trade-marks and an important alphabetic list of natural products and chemicals used in the ceramic and glass industries.

The book, bound in cloth, sells for 43 francs in Paris, 45 francs in the departments and colonies, and 50 francs abroad.

The World's Largest Telescope

(*Continued from page* 47)

measured with such an instrument as a photoelectric amplifier. The loss of the light obstructed by the observer's house is unimportant, because it is so small a fraction of the whole light received and also because the central part of the mirror must be covered in any reflecting telescope.

An exceptional feature of the 200-inch telescope will be its great angular aperture. In most reflectors the focal length is five or six times the diameter of the large mirror. The focal length of the 200-inch will be only 3.3 times its aperture. Thus the photographic intensity of a given star at its focus will not be merely four times that of the same star at the focus of the 100-inch telescope, but more nearly ten times as great. This means that the 200-inch telescope should penetrate fully three times as far into space, and thus open for investigation an unexplored sphere of about thirty times the volume of that hitherto sounded.

The observations mentioned above are to be made at the primary focus of the 200-inch mirror. In other classes of work different arrangements are called for. A convex mirror about forty inches in diameter, mounted at the centre of the tube below the observer's house, can be instantly turned into position by an electric motor. This will cause the light rays to converge less rapidly, and form an image of a field of stars on a photographic plate about seventeen inches square just below the 200-inch miror, which will be pierced with a central hole to transmit the beam. Or the photographic plate holder can be swung aside and replaced by a spectograph. Because of the varying refraction of the atmosphere, the star images cannot be held precisely in place by the driving clock of the telescope. An observer, carried by the massive tube, must watch a star under considerable magnification and, with the aid of suitable mechanism, make the small corrections necessary to keep it in position at the intersection of two cross hairs or on the slit of the spectrograph.

When longer spectrographs or other auxiliary instruments are needed to analyze the light of stars or nebulæ or to measure their radiation, one or more plane mirrors can be swung into position, displacing the focus to apparatus on either side of the telescope tube or in a fixed constant temperature chamber due south of the polar axis. In this way it will be possible to photograph the spectra of the brighter stars on a scale as great as that ordinarily used in the study of the sun.

The selection of a suitable site for the 200-inch telescope is not an easy problem. Should it be north or south of the equator, and at what latitude? For instruments up to one hundred inches aperture this might prove to be a difficult question, as the southern stars have been explored much less completely than those of the northern sky. But for a 200-inch telescope, which must be devoted exclusively to work beyond the range of smaller instruments, there can be no manner of doubt. The selection of celestial objects for special study cannot be made intelligently without the aid of all the knowledge available. As this is far more abundant for the northern heavens, a site north of the equator is evidently needed. As for its latitude, it is obviously desirable to include as much of the sky as possible, without depressing the north celestial pole too far. A latitude between 30 degrees and 35 degrees, where three-fourths of the entire heavens are visible, is thus indicated.

Much clear weather is wanted, and this means a site far removed from the paths of the principal storms, which cross the United States from west to east near the Canadian border and from south to north along the Atlantic coast. Great distance from storm centres is also favorable to sharp definition of star images, a prime requirement. As the unsteadiness of these images is naturally greater in the denser and more disturbed air of low altitudes, a high altitude is required, where the loss of light by atmospheric absorption is also low. But the site must not be too high, because of the extremely low temperatures and the consequent distortion of the telescope mirror when it is exposed to the sky at night (it is tightly enclosed in a nearly constant temperature case throughout the day). Local causes of disturbance, such as winds, electric lights, and so forth, must also be borne in mind.

Finally, the easy accessibility of cooperating laboratories and observatories is of vital importance. After previous study of these questions in selecting the site of the Mount Wilson Observatory thirty years ago, combined with the work accomplished since that time with many telescopes up to one hundred inches in diameter, it is clear that a site should be chosen not far distant from the many observatories, laboratories, and instrument shops in and near Pasadena. Although comparative telescope tests of several neighboring mountain summits have been made during the past five years, a final decision has not yet been reached.

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